Average Pause Ratio as an Indicator of Cognitive Effort in Post-Editing: A Case Study

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Abstract

Pauses are known to be good indicators of cognitive demand in monolingual language production and in translation. However, a previous effort by O'Brien (2006) to establish an analogous relationship in post-editing did not produce the expected result. In this case study, we introduce a metric for pause activity, the *average pause ratio*, which is sensitive to both the number and duration of pauses. We measured cognitive effort in a segment by counting the number of complete editing events. We found that the average pause ratio was higher for less cognitively demanding segments than for more cognitively demanding segments. Moreover, this effect became more pronounced as the minimum threshold for pause length was shortened.

1 Introduction

A fundamental objective of machine translation is to reliably produce high quality translations. Much progress has been made in automatically rating the quality of MT production (see O'Brien, 2011 for a discussion), and, over time, incorporating ratings into MT systems could reduce the need for post-editing. However, post-editing remains a significant activity that involves considerable human effort. A better understanding of the factors that contribute to post-editing effort is important, since the level of effort expended by the post-editor is closely tied to productivity.

Our understanding of post-editing effort is still far from complete, although there is a growing body of research on its nature. An important early contribution was the work of Krings (2001). He classified post-editing effort into three distinct categories: temporal (time spent), cognitive (mental processing), and technical (physical action). In his view, temporal effort results from a combination of cognitive and technical effort. Temporal and technical effort can be measured accurately with the help of modern technology.

Total post-editing time is the most basic measurement of temporal effort, but researchers have also used keystroke logging and eye-tracking to measure pause times or gaze duration (e.g., Krings 2001; O'Brien 2004; O'Brien 2005; O'Brien 2006; Dragsted and Hansen 2009; Carl et al. 2011).

Technical effort is the work involved in the keyboarding and mouse actions needed to make changes to the MT output. It can be measured by using logging technology to count the various possible actions, including insertion, deletion, cutting, and pasting (e.g. Krings 2001; O'Brien 2004; O'Brien 2005; O'Brien 2006). Aikawa et al. (2007) used a character-based metric to gauge the variation between MT and post-edited texts. Another approach is to use automatic metrics to measure the distance between the MT text and its final post-edited version (e.g. Tatsumi 2009; Temnikova 2010; Koponen 2012).

On the other hand, the mental processing involved in cognitive effort cannot be measured so directly. Researchers have investigated several approaches to measuring post-editing effort and the factors that contribute to it. These include rating the translatability of the source text (e.g. O'Brien

2006), rating post-editing difficulty in the MT text through think-aloud protocols (Krings 2001), choice-network analysis (O'Brien 2005; O'Brien 2006), ranking classifications of error difficulties (e.g. O'Brien 2006; Temnikova 2010; Koponen 2012), or effort ratings (e.g. Specia et al. 2009).

In this paper, we propose a new approach to measuring cognitive effort in post-editing. We classify post-edited segments as having required more or less cognitive effort on the part of the post-editor based on a metric that counts the number of *complete editing events*. In many circumstances, collections of individual editing actions can be considered to naturally form part of the same overall action, which is what we label as a complete editing event. For example, the insertion of a word by typing three characters separated by pauses is classified as a single complete editing event, not three separate editing events. This highlights the possible role of clusters of short pauses as indicators of cognitive effort. It suggests that total pause time in a segment may not by itself be an accurate indicator of cognitive effort in post-editing. This prompts us to introduce a new pause metric for segments and to investigate how it relates to our technical measure of cognitive effort.

Pauses, measured by keystroke logging or by eye tracking data on fixations and gaze duration, are known to be good indicators of cognitive demand in monolingual language production (e.g., Schilperoord 1996) and in translation and interpreting (e.g. Krings 2001, Dragsted and Hansen 2008, Shreve, Lacruz, and Angelone. 2011; Timarová, Dragsted, and Hansen 2011). It is therefore natural to expect pauses in post-editing to be indicators of cognitive demand. Surprisingly, previous post-editing studies did not find significant evidence for a relationship between pauses and cognitive demand (O'Brien, 2006). O'Brien compared the *pause ratio* (total time in pause divided by total time in segment) for machine translated segments where the source text had different concentrations of negative translatability indicators. These are linguistic features, such as passive voice, long noun phrases, or ungrammatical constructs, which are known to be problematic for machine translation. O'Brien predicted that segments with one or more negative translatability indicators would result in greater cognitive demands on the post-editor. She hypothesized that increased cognitive load should correspond to increased pause activity, as measured by the pause ratio, which she computed using pauses with a duration of at least one second. However, she subsequently found no significant difference in pause ratios for more or less cognitively demanding segments.

Nevertheless, the research cited previously in monolingual language production and in translation and interpreting provides strong evidence that there should be a relationship between cognitive load and pause activity in any environment involving reading and language production, including post-editing. This suggests that in O'Brien's study either the measurement of cognitive load or the metric for describing pause activity were insufficiently sensitive to reveal the expected effect. To follow up on O'Brien's initial investigation of this area and to dig deeper into these issues we conducted a case study in which we changed both the measurement of cognitive load and the metric for the pause activity.

O'Brien (2006) predicted that cognitive effort in post-editing would depend on features of the source text that would make it more or less difficult to translate by machine. This assumes the MT will be harder to post-edit when the source text has negative translatability indicators than when it does not. However, this is an indirect measure of cognitive effort in post-editing. To obtain a more direct measure, we focused on actual post-editing activity. Each post-editor is likely to experience different challenges, depending on his or her experience. Accordingly, we assessed the cognitive demand imposed by each segment using a measure of technical effort. We counted the number of complete editing events. We used this measure of technical effort to classify the post-edited segments into two categories (more or less cognitively demanding) depending on whether there were more or fewer complete editing events in the segment under consideration.

Pause activity can manifest itself in a variety of ways that cannot be discriminated by a measure based on total pause time in the segment. Pauses are of variable length, and a large number of short pauses will likely indicate a different cognitive processing/effort pattern than a single pause of thesame overall duration. Such differences can be captured to some extent by using the *average pause ratio*, which is computed for each segment as the average time per pause in the segment divided by the average time per word in the segment. We used these alternative assessments of cognitive load and pause activity to search for the expected relationship between cognitive load and pause activity in post-editing.

2 Method

The participant in the case study (L1 English and L2 Spanish) was a professional translator with 25 years experience as a freelance translator, 13 years of classroom experience in editing translations for pedagogical purposes, and four years of experience as a literary translation journal editor. He had no previous experience with post-editing machine translated text and no experience with software manuals.

The volunteer participant was seated in a quiet office and was asked to post-edit a MT text to his satisfaction. The text was part of a software instruction manual in English and that had been machine translated into Spanish using a phrase-based Moses system. No time constraint was imposed. The text was divided into segments roughly corresponding to sentences. Segment length ranged from 5 to 38 words with a mean of 19.4 words (median 23 words.). There were a total of 15 segments. The materials are included in Appendix A.

The Translators Workbench program from SDL Trados was used to present segments one by one on a computer screen, with the source text segment appearing at the top of the screen and the TM-proposed MT segment underneath. The participant was asked to post-edit the MT segments, and a keystroke log was recorded using the Inputlog keystroke logger.

3 Rationale

The post-editing of a segment can be broken down into the following steps:

- Reading of the presented source and target text segments
- *Problem recognition* based on a comparison of the source text segment with the target text segment
- Decision to act (accept, revise, or reject and re-write) the target text segment based on problem recognition results
- *Solution proposal* for identified translation problems if a decision is made to revise or re-write
- Post-editing action based on a selected solution proposal
- *Solution evaluation* of post-edited segment result
  - If not acceptable, revise or re-write again
  - If acceptable, continue to the next segment.

These steps are based on Angelone's (2010) three-stage behavioral model for uncertainty management in translation. The first stage, reading, invokes "the ability to extract visual information from the page and comprehend the meaning of the text" (Rayner and Pollatsek, 1989) and of the MT text. The stages identified by Angelone were *problem recognition*, *solution proposal*, and *solution evaluation*. These three stages are the most likely loci for cognitive effort in the active production part of post-editing, and it is natural to expect this effort to be observable in the pause data.

Indeed, we inferred very different pause patterns in the different steps of the post-editing process, based on keystroke observations. In particular, there were distinctive distributions of long and short pauses at each stage. For the purposes of the discussion below, short pauses are those that last for less than two seconds, while long pauses last at least five seconds. We frequently observed clusters of long pauses during the reflective stages of reading, problem recognition, and solution proposal, stages that place high cognitive demand on the post-editor. Final decision to act was often preceded by a single short pause. It was also notable that concentrated clusters of short pauses tended to accompany complex post-editing action; these clusters appear to be additional indicators of high cognitive demand. Finally, during the solution evaluation phase we again observed clusters of long pauses, which are again associated with high cognitive demand.

These observed patterns of long and short pauses appear to correspond in different ways to the cognitive effort expected at each stage. In particular, high cognitive load appears to be associated with both long pauses and clusters of short pauses. The *pause ratio* (total time in pause divided by total time in segment) does not take different patterns of pause behavior into account. In particular, it is not sensitive to the existence of clusters of short pauses. This prompted us to introduce the *average pause ratio* (average time per pause in a segment divided by average time per word in the segment) as a measure that is sensitive to different distributions of long and short pauses.

We consider illustrative examples to highlight the distinction between pause ratio and average pause ratio for segments. Take as a baseline a twenty-word segment that takes 80 seconds to post-edit, including a total time of 40 seconds in several pauses of varying duration. Regardless of the number and duration of individual pauses, the pause ratio for such a segment will always be 40/80 = 0.5. Now consider three distinct pause patterns outlines in Table 1 below, each consistent with the baseline description.

Case	Number of 1 sec pauses	Number of 20 sec pauses	Total pauses in segmen t	Pause time in segment (secs)
A	0	2	2	40
B	20	1	21	40
C	40	0	40	40

Table 1: Examples of segments with varying pause distributions, but the same overall time in pause

To compute the average pause ratio in any of these scenarios, we need to compute the average time per pause and the average time per word. See Table 2 below. The *average time per word* is the same in all three scenarios. It is:

(total time in segment)/(# of words in segment).

Thus, the average time per word is 80/20 sec = 4.0 sec.

However, the *average time per pause*, computed as:

(total time in pause)/(# of pauses in segment),

is different in each of the three scenarios. This is because the number of pauses varies from scenario to scenario, due to the different patterns of individual pause durations, while the total time in pause (40 sec) is the same in each scenario.

Case	Average time per pause (sec)	Average time per word (sec)	Average pause ratio
A	20	4	5.0
B	1.9	4	0.48
C	1	4	0.25

Table 2: Examples of average pause ratios

To summarize, these examples serve to illustrate the sensitivity of the average pause ratio to different pause patterns that do not affect the pause ratio.

It is also worth noting the effect of extending the total pause time, For example, if scenario A were modified so that there were four 20 second pauses instead of two, the average time per pause would still be 20 sec, but the total time in segment would increase to 120 sec, causing the average time per word to change to 120/20 sec = 6 sec. As a result, the average pause ratio would change from 5.0 to 20/6 = 3.3. In this situation, the pause ratio would also change - from 0.5 to 0.67.

4 Results

Intuitively, as the number of complete editing events rises, the level of overall cognitive demand experienced by the post-editor should increase. We classified the post-edited segments as *more cognitively demanding* when there were 4 or more complete editing events and *less cognitively demanding* when there were 2 or fewer complete editing events.

In order to create a clear separation between the two categories, we chose to remove from analysis the two segments with 3 complete editing events. (However, we note that the results we obtain would not have been significantly different if we had included the segments with 3 complete editing events in the less cognitively demanding group.) The choice of how to separate the more demanding group of segments from the less demanding group was based on clear breaks in the distribution of complete editing events around the median of 4.

It is important to emphasize that a large scale experimental study involving several individuals is needed to scientifically explore the way in which cognitive effort is related to the number or concentration of complete editing events.

Of the 13 segments analyzed, 8 were more cognitively demanding and 5 were less cognitively demanding. Data about the distribution of edits in each category is given in Table 3 below.

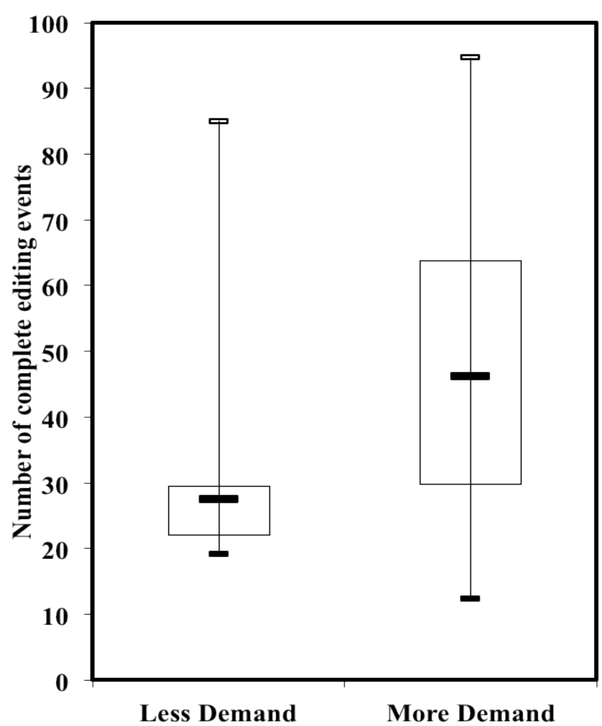

Figure 1: Boxplots of the distributions of complete editing events for more and less cognitively demanding segments

The length distribution of the more cognitively demanding segments (mean 19.0 words) was comparable to that for the less cognitively demanding segments (mean 17.2 words). See Figure 2 below.

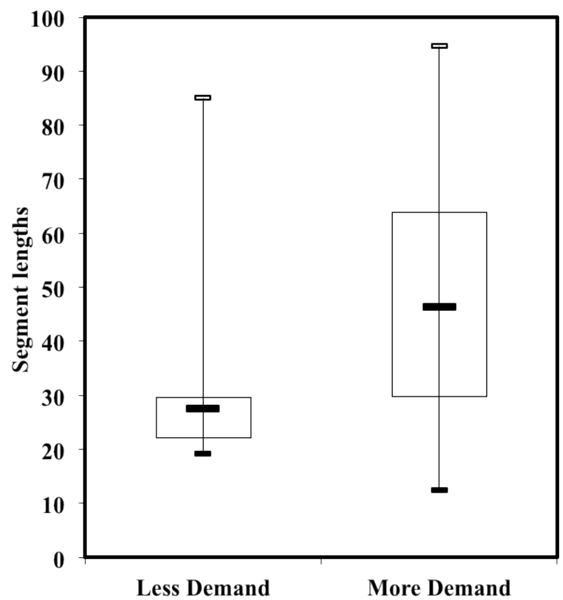

Figure 2: Boxplots the distributions of segment lengths for more and less cognitively demanding segments

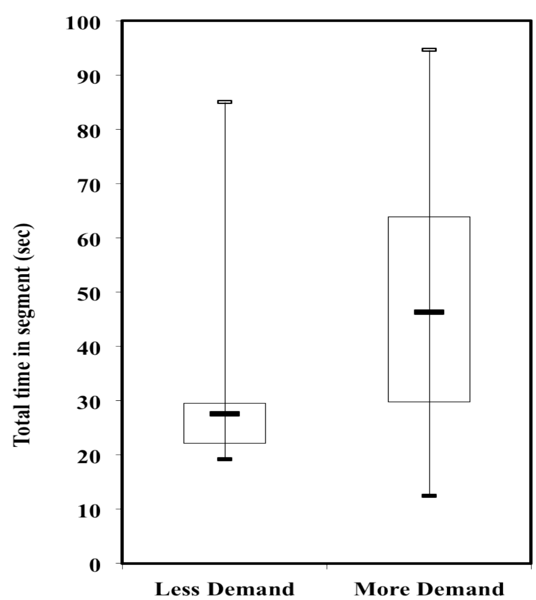

Figure 3: Boxplots of the distributions of total time in segment (sec) for more and less cognitively demanding segments

For more cognitively demanding segments total post-editing time (mean 111.5 sec) and total time in pause (48.2 sec) was longer than for less cognitively demanding segments (62.0 sec and 36.7 sec, respectively.) See Figures 3 and 4.

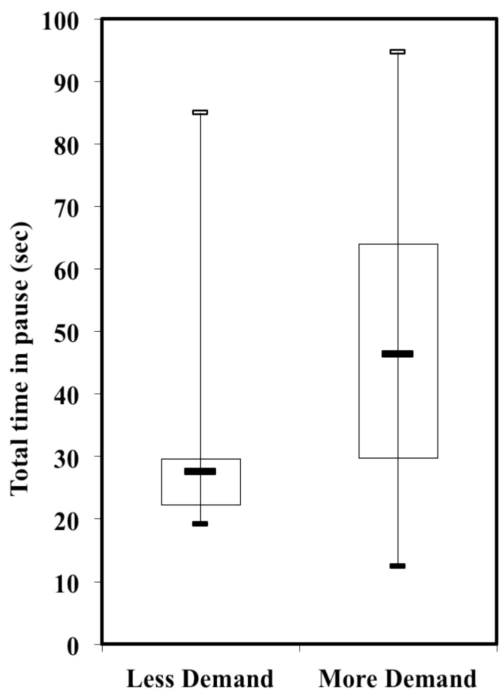

Figure 4: : Boxplots of the distributions of total time in segment (sec) for more and less cognitively demanding segments

We predicted that more cognitively demanding segments would have many short pauses associated with the monitoring of the higher number of post-editing actions. The predominance of short pauses should result in a low average pause ratio. On the other hand, in less cognitively demanding segments most of the effort would be in reading comprehension, problem recognition, and solution evaluation, where we typically found clusters of long pauses. The predominance of long pauses should result in a high average pause ratio.

In more cognitively demanding segments, pause ratio for pauses longer than 1 second was 0.42, while for less cognitively demanding segments it was 0.51. (See Figure 5.) A one-tailed independent samples t-test showed the pause ratio for less demanding segments was not significantly greater than for more demanding segments, $t(11) = 1.16$, $p = .13$.

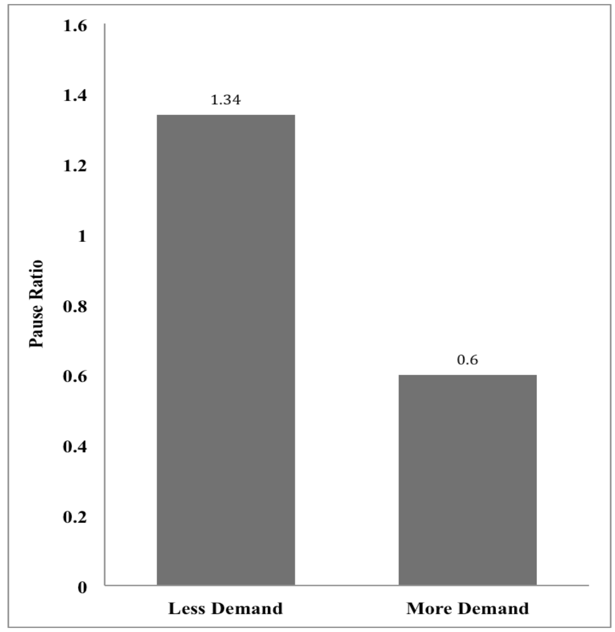

Figure 5: Pause Ratio for More and Less Cognitively Demanding Segments

O'Brien (2006) found that pause ratio in post-editing was not changed when her indirect measurement of cognitive load (based on features of the source text) was increased. The present result indicates that pause ratio is also unchanged when our more direct measurement of cognitive load (based on post-editor behavior) is increased.

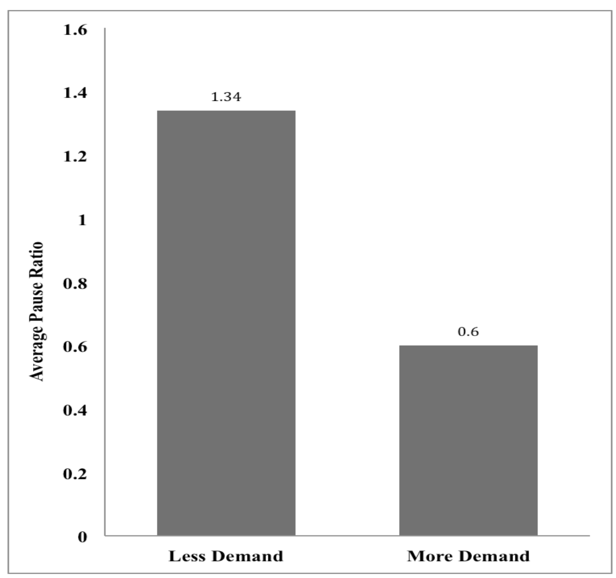

Figure 6: Average Pause Ratio for More and Less Cognitively Demanding Segments

On the other hand, in more cognitively demanding segments average pause ratio for pauses longer than 1 second was .60, while it was 1.34 for less cognitively demanding segments. (See Figure 6.) A one-tailed independent samples t-test showed the observed average pause ratio for less demanding segments was significantly higher than that for more demanding segments, $t(11) = 2.63$, $p = .01$. This indicates that average pause ratio decreases as predicted when our output measurement of cognitive load is increased.

We also computed average pause ratios for three different minimum pause durations: half-second, one second, and two seconds. As this lower threshold decreases, more cognitively demanding segments should gain more (short) pauses than less cognitively demanding segments. Consequently, although the average pause ratio for both types of segment should decrease, the predicted variation in average pause ratio should become more marked.

As predicted, the number of pauses in more cognitively demanding segments increased faster than the number of pauses in less cognitively demanding segments as the minimum pause length was reduced. See Figure 7.

Moreover, the results we found for the 1-second minimum pause threshold continued to hold for other threshold levels. The pause ratios corresponding to each minimum pause threshold level were not significantly different for more and less cognitively demanding segments. (See Figure 8.)

However, as predicted, more cognitively demanding segments had significantly smaller average pause ratio than less cognitively demanding segments, and this effect became proportionally more marked as the lower threshold for pause time was reduced. (See Figure 9.)

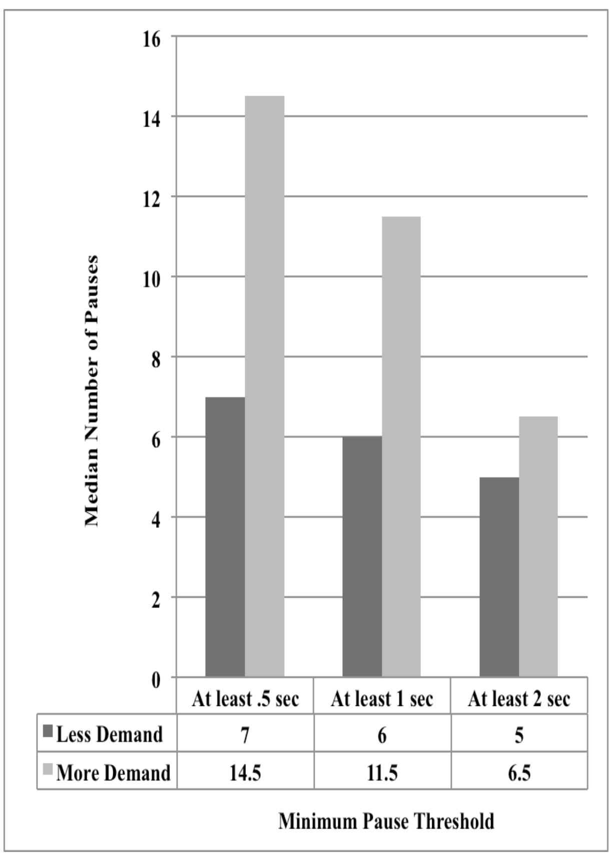

Figure 7: Median Number of Pauses at Different Minimum Pause Thresholds

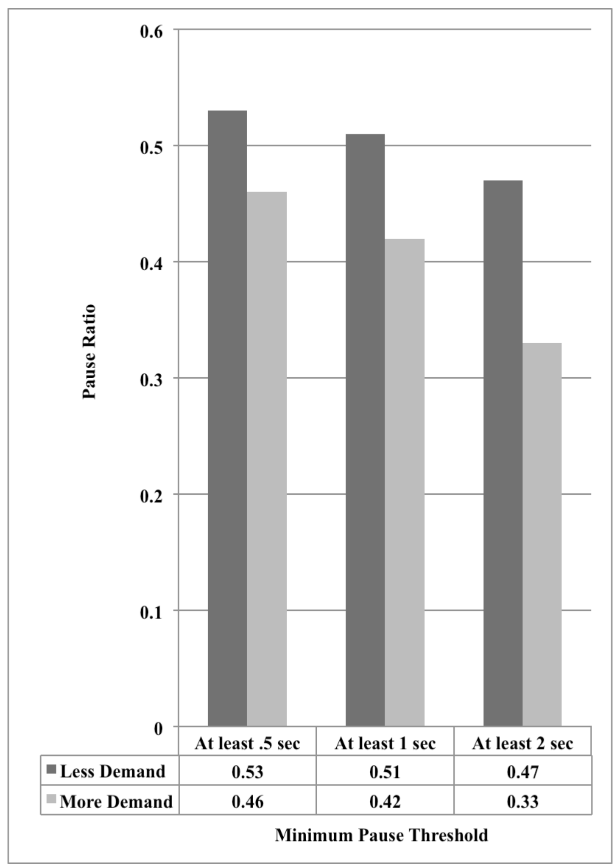

Figure 8: Means of Pause Ratios at Different Minimum Pause Thresholds

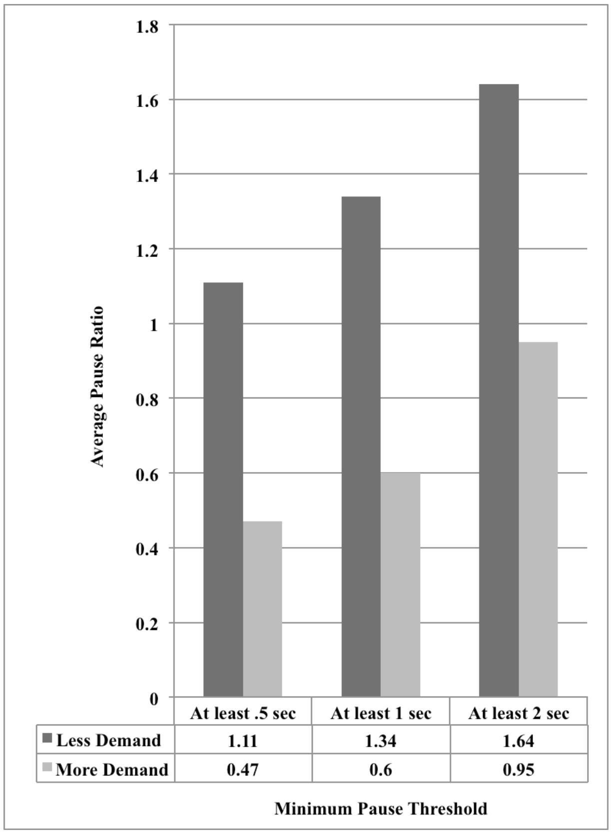

Figure 9: Means of Average Pause Ratios at Different Minimum Pause Thresholds

5 Conclusions and future directions

The main contribution of this paper is the identification of the average pause ratio metric as a potentially valid measure of cognitive demand. However, it is important to emphasize that our results are based on a case study of post-editing behavior in a single individual using a small number of MT segments. Our findings cannot be generalized to other situations without careful experimental replication involving several individuals and a larger segment pool.

We found a relationship between cognitive demand and average pause ratio: for more cognitively demanding segments the average pause ratio was smaller than for less cognitively demanding segments. This difference was significant for pauses longer than .5, 1, and 2 seconds.

Furthermore, we found that as the pause length threshold decreased the proportional difference between more and less cognitively demanding segments became greater. These effects are consistent with our observation that post-editing actions are often accompanied by a proliferation of short pauses.

Cognitive demand was measured by counting the number of complete post-editing events in the post-edited text. It is important to investigate the impact of individual differences on this measure. A subsequent goal would be to predict cognitive demand on the post-editor, not from the actions of the post-editor, but from characteristics of the target text itself - and eventually from characteristics of the source text.

A systematic investigation of the patterns of pauses we observed in this case study has the potential to provide a means to reliably delineate the different stages of the post-editing process through pause patterns. This could be done empirically, for example by varying error type and error location in target text segments.

The scope of the effect of error type on cognitive demand should also be investigated. Some MT errors result in significant loss of meaning, while other errors have a more superficial impact. Is there a relationship between the type of MT error and the pattern of pauses? When errors cause significant loss of meaning, is it easier for the post-editor to re-write rather than to post-edit?

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Appendix A: Sample Materials

Less cognitively demanding segments (0-2 complete editing events):

ST: Google Docs has a revision history pane that allows you to view at a glance all changes made to a doc by each collaborator.
MT: Google Docs tiene un panel Historial de revisiones que le permite ver de un vistazo para todos los cambios realizados en un documento por cada colaborador.
PE: Google Docs tiene un panel Historial de revisiones que le permite ver de un vistazo todos

los cambios realizados en un documento por cada colaborador.

ST: Click a time stamp in the right column to see what changes were made at a given time or use the arrow keys to scan through many revisions quickly.
MT: Haga clic en una marca de fecha y hora en la columna de la derecha para ver qué cambios se han realizado en un momento determinado o utilice las teclas de flecha para escanear a través de numerosas revisiones rápidamente.
PE: Haga clic en una marca de fecha y hora en la columna de la derecha para ver qué cambios se han realizado en un momento determinado o utilice las teclas de flecha para revisar numerosas revisiones de forma rápida.

ST: If you'd like to revert to the version you're currently viewing, click Restore this revision.
MT: Si desea revertir a la versión que está viendo, haga clic en Restaurar esta revisión.
PE: Si Ud. desea revertir a la versión que está viendo, haga clic en Restaurar esta revisión.

More cognitively demanding segments (3 or more complete editing events):

ST: For example, James, whose edits show in orange text, deleted and added text while bmichael, whose show in green text, removed a paragraph and added a comment.
MT: Por ejemplo, Juan, cuyos cambios se muestran en naranja texto, elimina y se agrega texto al bmichael, cuyo texto aparezcan en verde, elimina un párrafo y se agrega un comentario.
PE: Por ejemplo, Juan, cuyos cambios se muestran en texto anaranjado, elimino' y se agrego' texto mientras que bmichael, cuyo texto aparece en verde, elimino' un párrafo y agrego' un comentario.

ST: Google spreadsheets sometimes trims down your revisions over time to save storage.
MT: Google hojas de cálculo a veces recorta hacia abajo las revisiones a lo largo del tiempo para guardar su almacenamiento.
PE: Las hojas de cálculo Google a veces reduce las revisiones a lo largo del tiempo para reducir la cantidad de almacenamiento necesaria.

ST: Note: Restoring your document to a previous version does not eliminate any versions of your document; rather this version moves to the top of your revision history, maintaining all previous versions of your document, including the current version.
MT: Note: Nota: restaurar el documento a una versión anterior no se eliminan todas las versiones del documento. En lugar de esta versión se mueve a la parte superior de su historial de revisiones, mantener todas las versiones anterior del documento, incluida la versión actual.
PE: No'tese: El restaurar el documento a una versión anterior no elimina todas las versiones del documento. En cambio esta versión se mueve al primer lugar de su historial de revisiones, manteniendo todas las versiones anteriores del documento, inclusive la versión actual.

ST: Visit the Revision Pruning help article to learn more about this process.
MT: Visite el artículo de ayuda de eliminación de revisión para obtener más información sobre este proceso.
PE: Para informarse ma's sobre este proceso, consulte el artículo de soporte sobre los Recortes de las revisiones.

Segment excluded from analysis (3 complete editing events):

ST: If you're working in Google spreadsheets, and your document is either large or you created it a long time ago, your revisions may be pruned.
MT: Si está trabajando en Google, hojas de cálculo, y el documento es grande o lo creó hace mucho tiempo, las revisiones se pueden cortar.
PE: Si Ud. está trabajando en las hojas de cálculo Google, y el documento o es grande o lo creó hace mucho tiempo, las revisiones se pueden recortar.