Noise exposure and cognitive performance – Children and the elderly as possible risk groups

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A general finding in studies of the effects of noise on cognition and human performance is that the task be performed has to be complex and cognitively demanding (cf Smith, 1989; 1992) to be negatively affected by noise. Tasks that are simple and repetitive are unaffected by noise, and if the task is boring, simple enough or well learned, noise may even improve performance. Thus, a search for noise sensitive tasks must focus on tasks and are have some complexity and are taxing the cognitive resources.

Cognition is a fairly covered area in psychological noise research. There are several well-controlled, recent studies that have compared the relative impacts on attention, reading, memory and learning (Cohen, Evans, Stokols & Krantz, 1986; Evans & Lepore, 1993; Evans & Hygge, 2002). There are also a few studies comparing different age groups on the same set of cognitive tasks. These studies are mainly experimental on thus employ acute noise exposure in laboratory like conditions. However, in a few cases there are longitudinal studies on how chronic noise exposure in children affects some of the very same cognitive processes studied with experimental acute noise exposure, which gives some opportunity to compare the impacts of acute and chronic noise.

Dose-effect relationships

For many reason, in particular for legal and regulation reasons, it is desirable that an evaluation of noise effects on cognition can be projected unto a dose-effect curve. The general forms of dose-effect relationships are shown in Figure 1, which are based on annoyance noise data from FICON (1992).

The curve to the right (dashed line) is taken directly from FICON (1992), which summarized empirical findings on noise annoyance. The curve to the left (solid line) is generated from the same equation as the right curve by adding10 L_{dn}-units. Since in the present context the relationships are meant to depict the general form of noise effects on just any performance or response the ordinate has been relabeled "Effect" and scaled from 0 to 100%. Any differences between various effects are thought of as being picked up by parallel shifts of the function along the abscissa or ordinate of the general dose-effect curve, and thus approach whatever slopes there originally are in the depicted curves.

Figure 1 – Two hypothetical dose-effect relationships between noise dose (L_{eq}) and percent effect (% Effect). Adapted from FICON (1992)

Since the basic interest here is the relative gain (or loss) in cognitive performance by lowering the noise dose, rather than the absolute performance at different noise levels, the relevant information is in the slope or 1st derivative of the noise-effect relationship. Plotting the noise-effect slopes for a few specific cognitive functions from different studies, will, if the grouping of the slopes come out in a coherent and orderly way, set a platform for statements about gains in cognitive performance as a result of lowered noise levels.

Thus, the relative loss (or gain) in percent of the effect studied at two noise levels, can be employed to build a family of straight lines. If these families of straight dose-effect lines form distinct and consistent clusters when grouped on which effect is studied and which groups are exposed, this method may prove valuable and reliable.

Comments on the theoretical properties of dose-effect functions

The curves depicted in Figure 1 are the accumulated effects at a given noise dose (L_{eq}, which in the present text always is understood as measured in dB(**A**)). This distribution function can be derived by integrating a corresponding normal distribution density function. On the assumption that a normal distribution correctly describes the underlying continuum, some general remarks can be made about these and related dose-effect functions.[1]

[1] Note, that even if it is assumed that the cumulative dose-effect curves for individuals are closer to a square-wave than to a normal distribution, a normal distribution for a larger sample may follow when the group average of the individual curves are formed.

1. They have their greatest change in response (% Effect) per one unit change in noise level (L_{eq}) where the slope of the curve has its maximum value, which is where the 1st derivative has its maximum, which is around the L_{eq}-point where there is 50% Effect.

2. At the beginning of the dose-curve, there is only a small change in response per dose unit.

3. At the end of the dose-curve, when the effect approaches 100%, there should also be only a small change in response per dose unit. Quite a few dose-effect curves that have been proposed in the research literature show monotonous increases in the slope with increasing L_{eq}, and no point of diminishing returns in slope. This is contrary to theoretical expectations, but is compatible with the assumption of an underlying normal distribution, if it is assumed that the curves with monotonous increases in slope only depict a restricted lower L_{eq}-range and do not include any points above the L_{eq}-point with the maximum slope).

4. Along the middle part of the ordinate (20-80% Effect), the ratio of change in response to one unit change in dose is rather narrow. In Figure 1 this ratio is around 3.

5. A parallel shift of the dose-effect curves along the abscissa, does not change its slope, i.e., does not change the 1st derivative.

6. A parallel shift of the dose-effect curves along the ordinate, does not change its slope, i.e., does not change the 1st derivative.

Thus, the estimates of how much can be gained in cognitive performance by lowering the noise dose, can under the given assumptions, be reduced to locating an upper and lower L_{eq}-point and assess the slope of the line connecting them.

Transforming the measurement scales of the responses

The ordinate in Figure 1 is a measure of percent Effect, which as a rule is not reported in the original studies. However, in studies where two or more different noise levels have been compared in how they affect performance, a crude ratio of performance improvement, or slope, when switching noise levels can be computed and entered into Figure 1, with a positive slope indicating impairment of the cognitive effect in question.

As an example, in a study by Boman (2003) long term recall (open-ended questions) and recognition (multiple choice questions) of a text read under 66 (speech noise) and 38-40 L_{eq} (quiet) was studied. The tests for recall and recognition was performed in quiet conditions more than an hour after reading the text. The mean recall scores for a group of young students (13-14 years) were 2.03 (noise) and 3.41 (quiet).. The improvement thus was 68.0 % of the performance in noise, stretching between around 40 and 66 L_{eq}, which equates to a slope close to 2.5 as shown in the top line in Figure 2. An arbitrary starting point of 10% impairing noise effect in the quiet condition has been added for all the dose-effect lines in the Figures. This arbitrary choice of starting point did not influence the slope of the corresponding line. For the recognition task in the same group and in the same noise condition, the improvement was 25%, which is also shown in Figure 2. To enhance interpretability the lower section of the solid line in Figure 1 (USAF + 10 L_{dn}) is added to this and the following Figures.

Figure 2 around here

Response types

In the paragraph above, results from an experimental study (Boman, 2003) on recall and recognition in a memory task was employed as an example of how to infer the slope of the dose-effect curve. That study also contained several other measures of cognitive performance in noise and quiet, and is one study in a set of three with the same experimental set-up, the same cognitive measures, and the same two noise sources. The two sources were road traffic and speech noise, matched on time patterns and set to 66 L_{eq}.

One of the reasons for including speech as noise is that when other people are talking, the debilitating effects may be more dramatic than for transportation noise. Several well-replicated studies have shown that performance is impaired when speech is heard and the subjects read and memorize verbal material (see e.g., Tremblay, Nichols, Alford & Jones (2000) for a recent overview). The effect or irrelevant speech is rather independent of its intensity, and has been reported from noise levels below 60 dB(**A**). The meaning of the speech sometimes is unimportant, since the negative effect has been found with foreign languages, reversed speech, as well as non-speech signals that have been made to have an acoustical variation in the signal that is similar to natural speech. This negative effect of speech and speech-like sounds seem to be on memory rather than on perception. However, most of the research on irrelevant speech and sounds (ISS) has employed a serial short-term memory recall task, and the pronounced negative effects seem to be more marked for serial recall tasks than for memory tasks that don't have a strong serial component.

The difference between the three studies is the age-group of the participants. In the first of these three studies (Hygge, Boman & Enmarker, 2003) the subjects were young adults (aged 18-20), in the second study (Boman, 2003) younger students (aged 13-14) were recruited, and in the third study (Enmarker, 2003) one group were teachers aged 35-45, another group teachers aged 55-65. For a full account of the layout of the study and the cognitive measures employed, see Hygge, Boman & Enmarker (2003).

Children and young adults

Experiments with acute noise

In Figure 2 the results for recall and recognition of the text are shown from Boman (2003) and Hygge, Boman & Enmarker (2003). As can be seen the strongest impairing noise effects are for the children aged 13-14 years on the recall when exposed to road traffic noise and speech noise while reading the text. The second strongest effects are for recall in the young adults.

Figure 3 around here

In Figure 3 the slope lines for a few other of the cognitive tasks in Boman (2003) and Hygge, Boman & Enmarker (2003) has been added. As can be seen none of them have much of a slope.

Hygge (in press) reported ten classroom experiments (*N* = 1358) with children aged 12-14 exposed to different noise sources at different noise levels. The children were exposed to noise while reading a text and tested for recall and recognition in quiet one week later. The text employed was similar to the text in Boman (2003), Enmarker (2003), and Hygge, Boman & Enmarker (2003) and thus some comparisons are justified. The plotted slope-line are shown in Figure 4.

Figure 4 around here

As can be seen, again the strong effects were on recall, not on recognition, and in particular for the aircraft noise and the road traffic noise at both the 55 and 66 dBA L_{eq}-levels. For recall after being exposed to road traffic noise, the slopes are close to those for recall for the children aged 13-14 in Figure 2. For aircraft noise the slopes in Figure 4 is steeper than for road traffic noise.

A field study with chronic noise exposure

Figures 2-4 and the studies behind them refer to experimental studies with acute noise exposure, with whatever shortcomings such studies have in their relation to real-life situations with chronic noise exposure.

Figure 5 around here

However, in the Munich airport noise study of children (Hygge, Evans & Bullinger, 2002), comparable data are available on effects of chronic noise on some of the cognitive functions depicted in Figures 2-4. See Figure 5!

Figure 5 shows the slopes for the difference in performance between the experimental (change in noise level) and control groups (stable noise levels across airport switch over) at the old airport before the close down of the airport, and at the new airport 1.5-2 years after the switch over. The recall task in the Munich study was designed to tap the very same characteristics of the recall test in the classroom studies. However, while the efficient independent variable in the classroom studies was the acute noise exposure, the independent variable in the Munich study was the amount of chronic aircraft noise. As can be seen, recall and reading a difficult word list were the two measures most strongly affected by the increase or decrease in aircraft noise. The slopes of these lines are actually steeper than the corresponding lines in Figure 2, indicating that in real life, chronic noise exposure at a given noise level is more potent in impairing cognitive functions than acute noise is.

The steep slopes in the Munich study in Figure 5 compared to acute noise exposure in Figures 2-4 are important to note for two different reasons. The first is that recall is a sensitive measure both to chronic and acute noise exposure. The second reason is that the real life situation in the Munich study produces a steeper gradient than the experimental acute noise data. These findings lends ecological validity to the choice of recall and reading as particularly noise sensitive cognitive abilities.

The noise levels reported for the Munich study are the outdoor levels, which is in contrast to the indoor levels given for the other studies in the present text. However, since the slope of the lines is the crucial thing, a shift to the left by the amount of the sound insulation properties of the school buildings is not important.

Middle-aged and older persons

Figure 6 around here

Figure 6 is basically the same as Figure 2 but with data from the two age groups (35-45 and 55-65) in Enmarker (2003). The addition to Figure 2 is the 67+ group, which is taken from Enmarker (1996), who did a study on retired people, older than 67 years, with basically the same tests and procedures as in the aircraft noise 66 dBA L_{eq}-condition in the classroom experiments. The four lines with the steepest slope all refer to recall, but among them there is no marked dominance for any of the three age groups.

Figure 7 around here

Figure 7 is organized in the same way as Figure 3, with data from the two age groups (35-45 and 55-65) in Enmarker (2003). As was true also for Figure 3, none of the lines in Figure 7 have much of a slope.

Direct comparisons between age groups

Figure 8 around here

In Figure 8 data from Figures 2-7 have been averaged and grouped to make comparisons between age groups possible on recall, recognition and the average of different other cognitive tasks, i.e.

the attention task and the word comprehension miscellaneous cognitive tasks (Cogn misc). Each of the relevant slopes in the lines in Figures 2-7 has been entered with their slope/dB-ratios. Averaging has been done across noise sources. The studies included have not been weighted for number of subjects. In the group children 13-14 years, the data from classroom experiments and the Munich study have been included. In the group 55+ (55 years and older) the 67+ group from Enmarker (1996) has been included. To enhance visibility and separation of lines, the ordinate has been expanded and a fixed endpoint constant of 15 and 20%, instead of 10%, has been added to lines Rcl 35-45 and Rcl 13-14.

The interpretation of Figure 8 is clear-cut. Recall is particularly vulnerable to noise in all age groups except the young adults 18-20 years, who are less sensitive and also are at their peak of this kind of episodic memory (Tulving, 1993).

Coupled with the data for reading of difficult paragraphs and word lists in chronic noise for children aged 9-12 in the Munich study, as shown in Figure 5, a tentative conclusion is that children are more vulnerable than other age groups. Further, language based abilities, such as reading, understanding and recalling, are the most vulnerable of the noise sensitive cognitive functions.

Although nothing is reported about chronic noise effects on cognition in older persons, data from acute noise experiments indicate that older persons are as vulnerable as children in their recall capacities.

A note on Noise aftereffects and motivation

Studies of aftereffects of noise are concerned with how performance is affected after the noise has been shut off. The task performed in the first phase of the experiment, when noise is present, is unrelated to the task performed in the second phase, which is in silence. Thus, there is nothing to be learned from the first noisy phase that can be used in the second silent phase. In such studies there is no learning situation, but any effects of the noise on the subsequent tasks in the silent phase, must have to do with a more general impact on motivation and persistence. Glass and Singer (1972) introduced studies on the aftereffects of noise. In the first phase of the experiment one group was exposed to noise while working on a relatively simple cognitive task, such as or adding numbers or finding the letter A in a lists of letters or words. Compared to a silent control group, the noise did not affect how good these tasks were performed. After the noise was shut off, the subject switched to another task, often endurance in solving insoluble geometrical puzzles, and sometimes proof reading of a text prepared with errors. Having encountered noise in the first phase reliably impaired the performance of these tasks. In addition to a silent control group and a noise group, Glass and Singer also had a noise group where the predictability of the noise bursts was high or where the subjects were given control over the noise source. Predictability was manipulated by letting the noise bursts come at fixed intervals and with fixed duration. Perceived control of the noise was introduced by a button next to the subject and the instruction to use it to shut off the noise if it became too disturbing, an opportunity almost no subject took advantage of. The predictability of the noise bursts or having been given perceived control over the noise reduced the noise aftereffects to that of the silent control group.

After Glass and Singer published their original work, a number of studies have replicated the aftereffects. More generally it has been shown that the aftereffects of uncontrollable and/or unpredictable stress is not restricted to noise, but has been shown also for indoor environment variables, crowding and work load (Cohen, 1980).

In the same way as for the ISS-effects there seem to be an abrupt rather than gradual onset of the aftereffects with increases in noise levels. Another similarity to the ISS-studies is the fact that quite a few of the noise aftereffect studies that have reported significant effects resulting from the manipulation of the control dimension, have employed sounds that have irrelevant speech as an important ingredient.

Discussion and conclusions

The studies on recall and reading cluster together and have slopes around 2.6. Studies on recognition, attention and other cognitive abilities also group together but have slopes that are less than 1.0.

Thus, for recall and reading in noise it can be expected that a reduction of the noise level by 5 L_{eq} would result in improved performance by something like 13%, at least when the reduction starts within the region 65-80 L_{eq}. For attentional tasks and for recognition memory, a 5 L_{eq} reduction in noise level is expected to only result in less than 5% improvement of the response.

A comparison between findings from the acute noise laboratory studies and the findings from the longitudinal Munich airport noise study corroborates that the conclusion than recall and reading are particularly noise sensitive cognitive abilities both in the lab and in the field.

Having said this, we must also be aware of a possible tension between a within-person or between-person approach to changes in noise levels. The traditional cross-sectionally construed dose-effect curves may not accurately predict the amount of change in effect when the noise-dose is changed. For instance, Griffith and Raw (1989) noted tendencies towards "overshoot", meaning that when a group received increased noise levels in their surroundings, their resulting annoyance reaction became higher than what a steady state cross-sectional dose-effect curve would predict. The reverse was also true, lowered noise levels resulted in less annoyance than what a cross-sectional dose-effect curve would predict.

As evidenced by the results from ISS-studies and aftereffect studies, the character of the noise source and the motivational effects induced by the setting in which the noise occurs, also are important determinants of the response magnitudes. This character or quality of the noise is not easy to incorporate into the quantification of the noise dose.

Concerning the method suggested here, plotting dose-effect lines, there are pitfalls. Making a crude conversion from performance scores to a cumulative curve with percent Effect can be questioned. Inferring percent impairment during a 24-hour day-night average implicit in the L_{eq}-measure from a 15-min exposure can also be questioned. However, the basic idea of pursuing this type of analysis is worthwhile. If the analysis comes out in an orderly way, some insights may be gained from the underlying ideas, however crude the conversions were. One important criterion of the usefulness of this analysis is whether the slopes for the interpolated straight lines are fairly equal within response types in comparable L_{eq}-regions, but differ between response types.

The approach outlined in the present paper, employing the slope or the 1st derivative of does-effect functions, is still at a preliminary stage. The strengths and weaknesses of the approach will become clearer when the effort has been taken on to add more empirical studies to the analyses.

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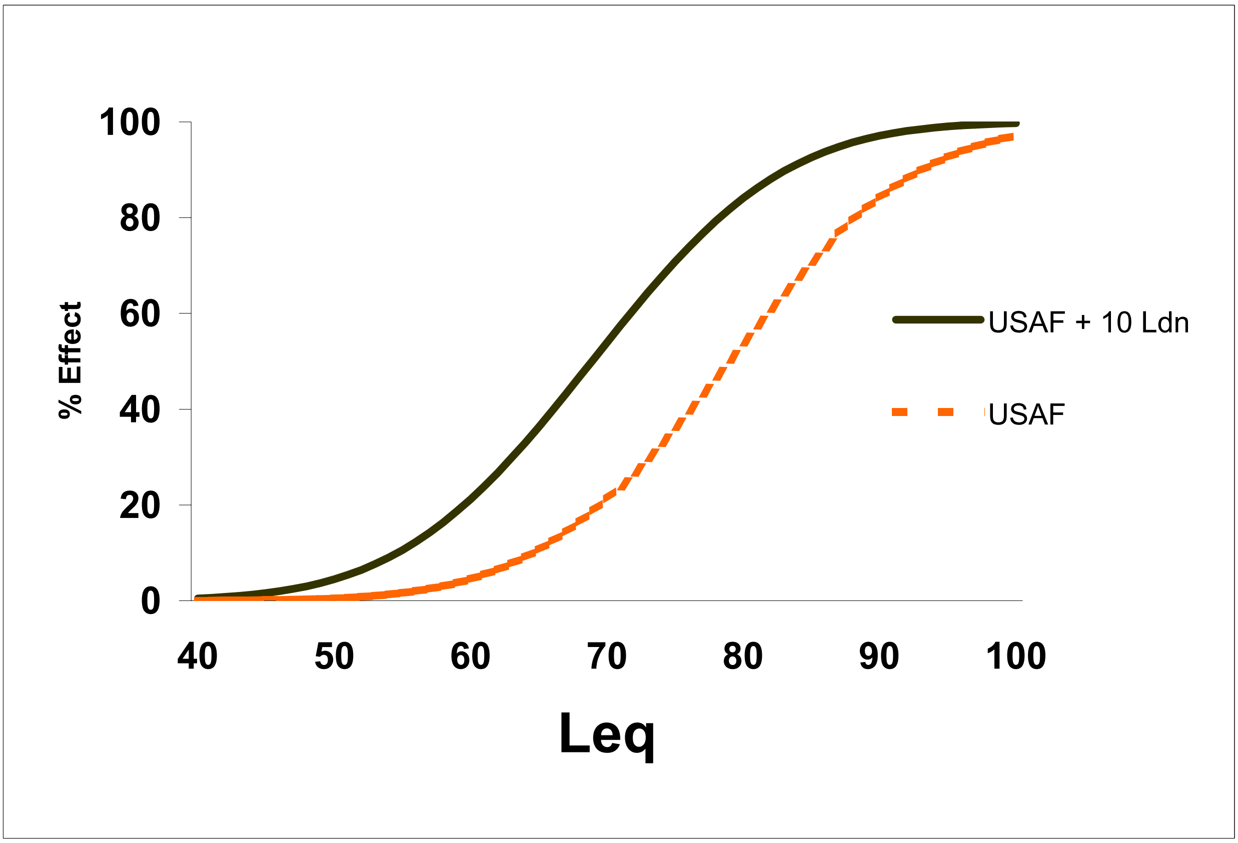

Figure 1. Two hypothetical dose-effect relationships between noise dose (Leq) and percent effect (% Effect). Adapted from FICON (1992)

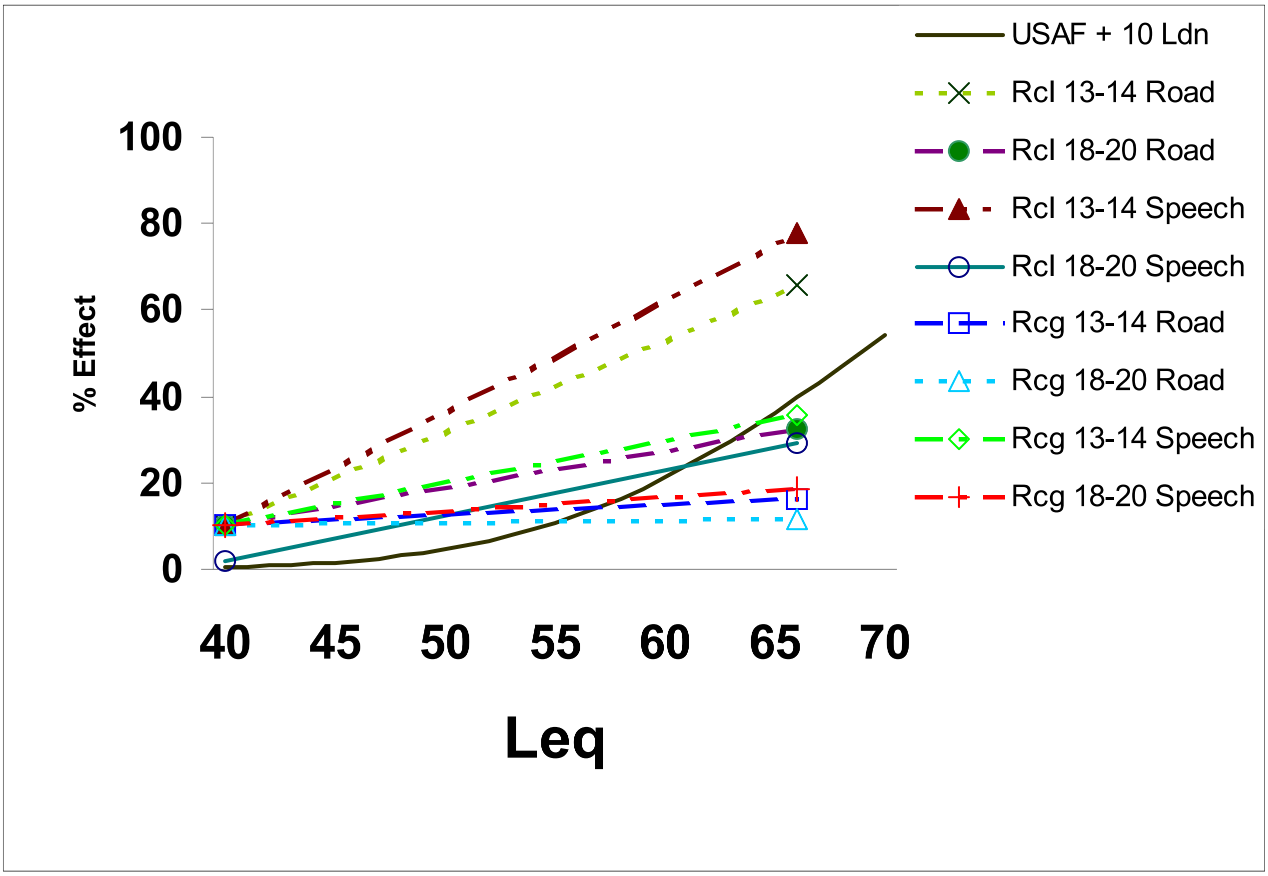

Figure 2. Hypothetical dose-effect curves and approximated results from studies of children (aged 13-14) and young adults (aged 18-20) in acute road traffic (Road) and speech noise (Speech) played back at 66 dBA L_{eq}. Rcl = recall of a text, Rcg = recognition of a text.

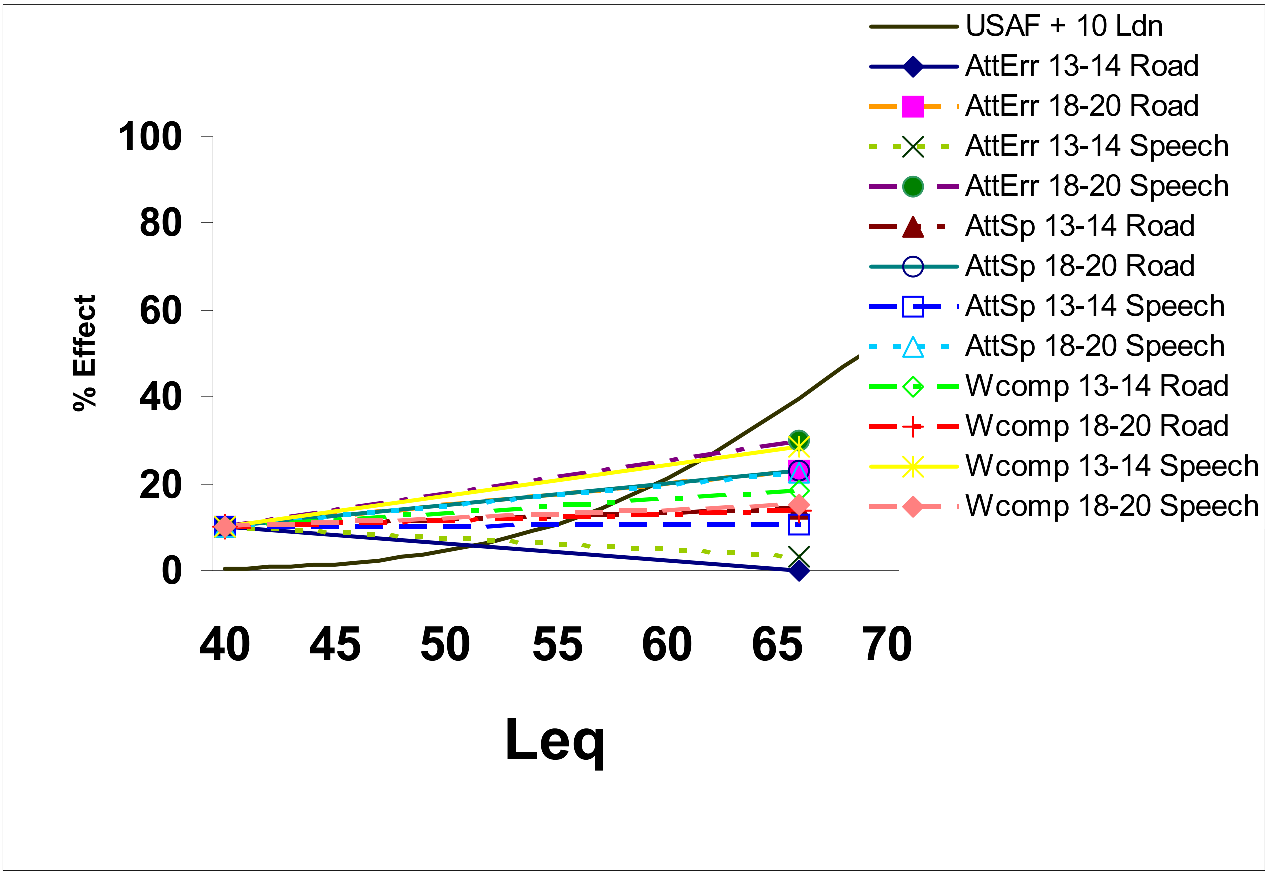

Figure 3. Hypothetical dose-effect curves and approximated results from studies of children (aged 13-14) and young adults (aged 18-20) in acute road traffic (Road) and speech noise (Speech) played back at 66 dBA L_{eq}. AttErr = errors in an attention task (search and memory task), AttSp = speed in the attention task, WComp = performance in a word comprehension task.

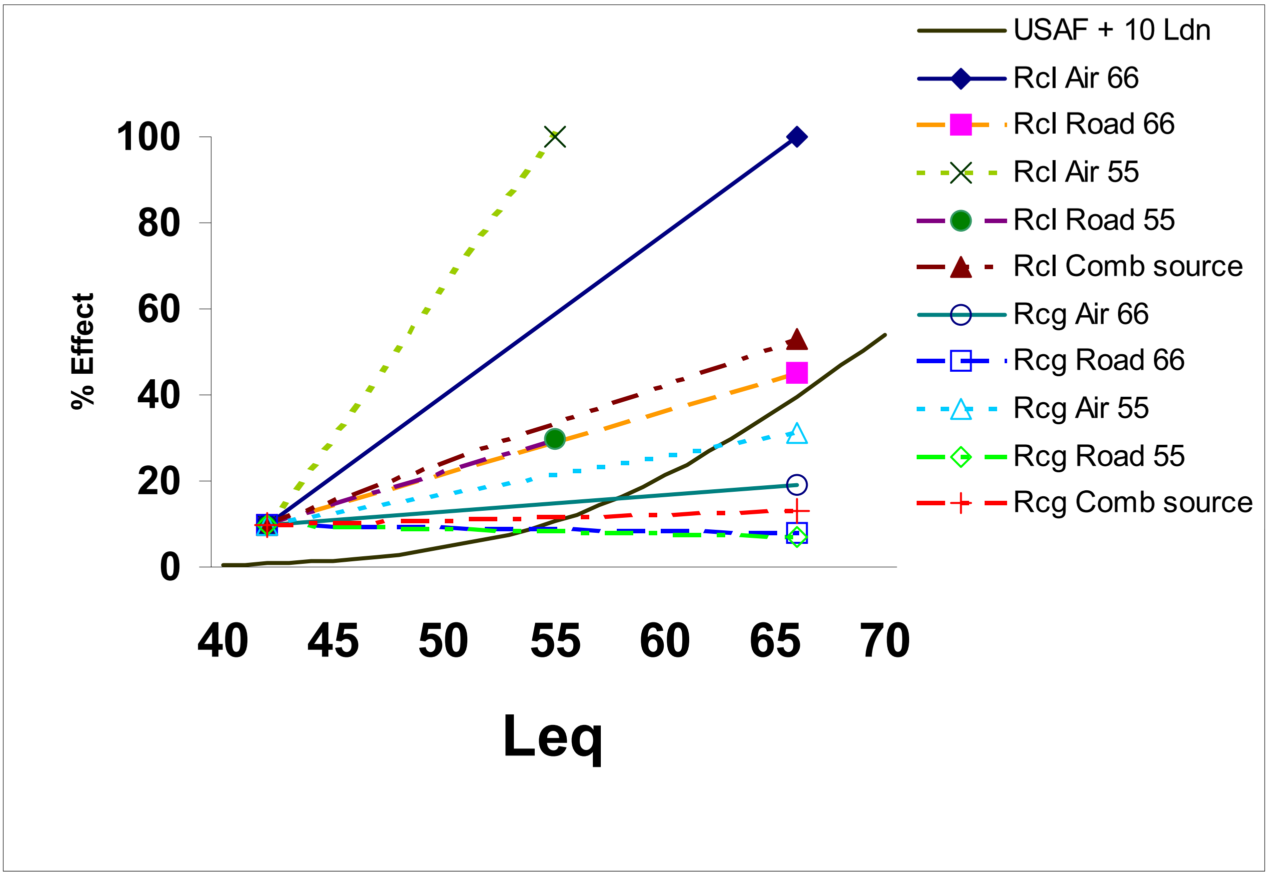

Figure 4. Hypothetical dose-effect curves and approximated results from studies of children (aged 12-14) in classroom experiments with different noise sources and at different noise levels. Rcl = recall of a text, Rcg = recognition of a text, Air = aircraft noise, Road = road traffic noise, Comb source = the average of different combined noise source conditions, 55 and 66 dBA L_{eq}-levels.

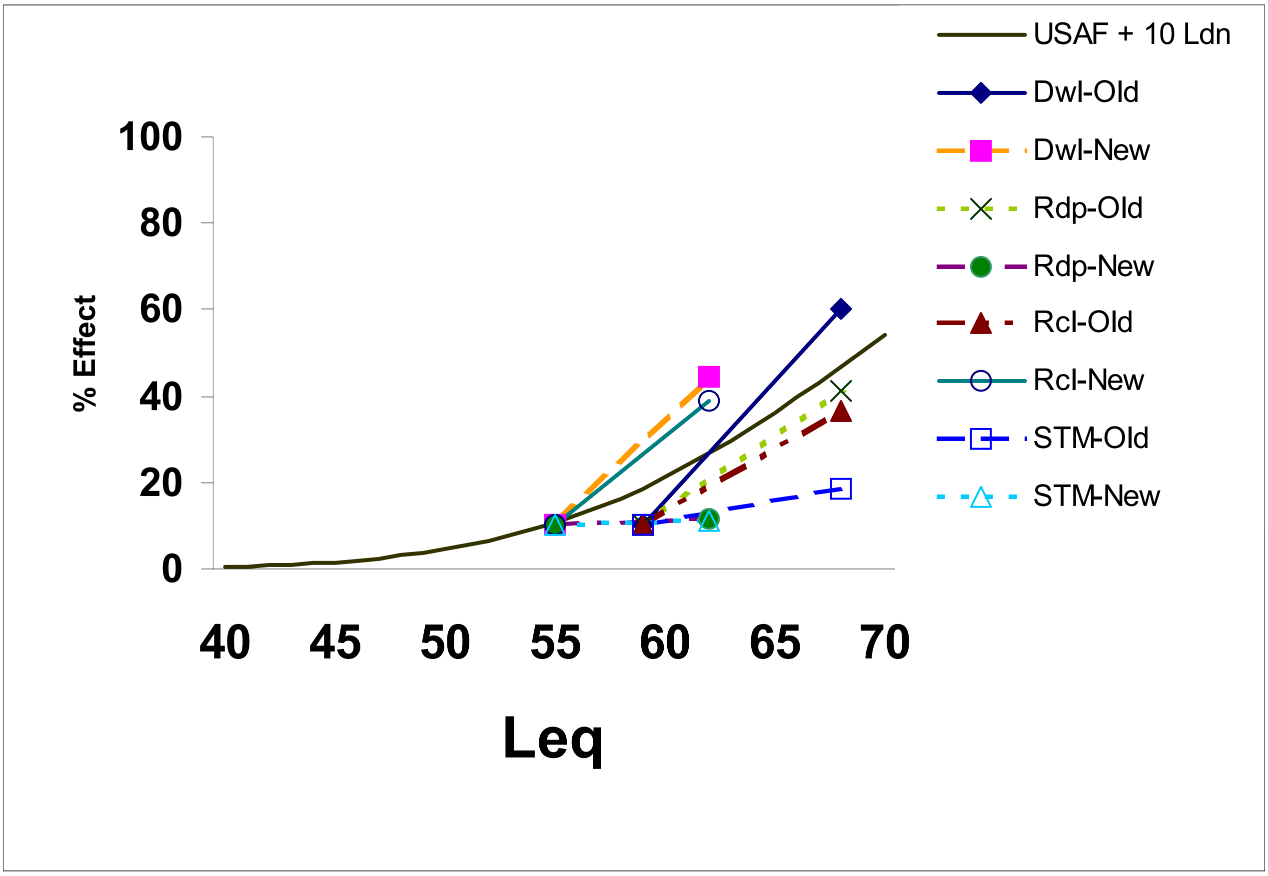

Figure 5. Hypothetical dose-effect curves and approximated results from the longitudinal Munich airport noise study of children (aged 9 at the start of the study). Old = old airport, New = new airport. Dwl = reading difficult word list, Rdp = reading difficult text, . Rcl = recall of a text, STM = short term memory.

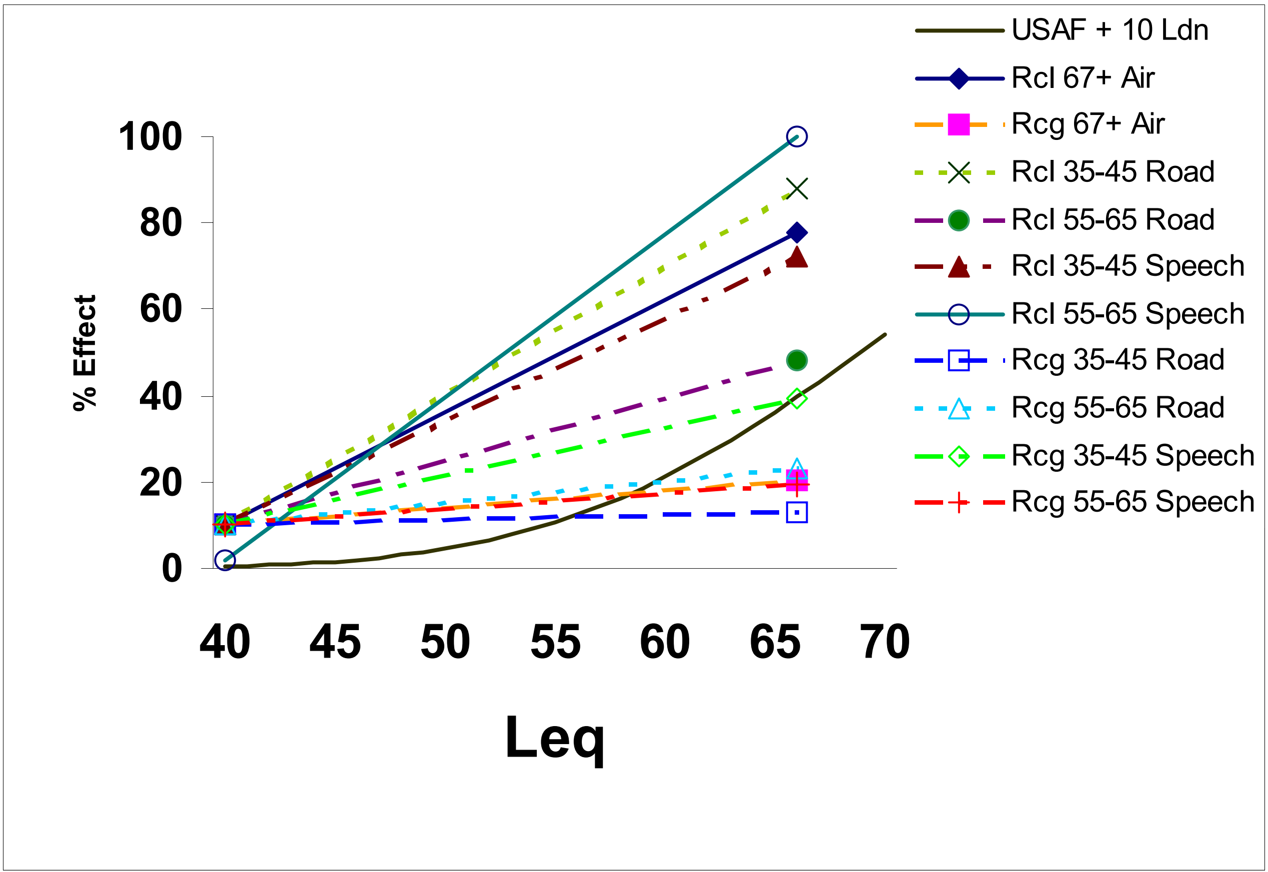

Figure 6. Hypothetical dose-effect curves and approximated results from studies of middle-aged (aged 35-45) and older persons (aged 55-65 and 67 or more). Rcl = recall of a text, Rcg = recognition of a text. Air = Aircraft noise, Road = road traffic noise, Speech = speech noise The noise was played back at 66 dBA L_{eq}.

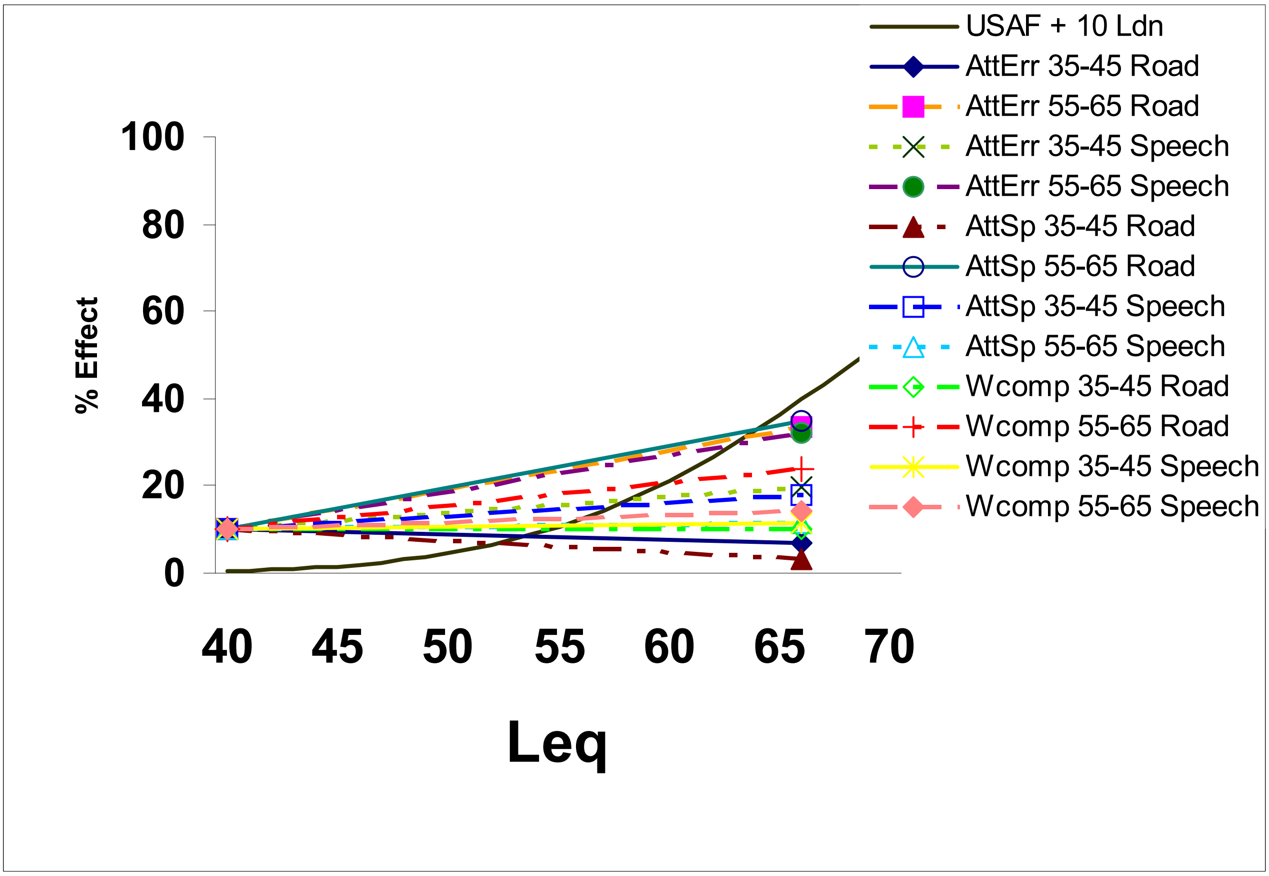

Figure 7. Hypothetical dose-effect curves and approximated results from studies of middle-aged (aged 35-45) and older persons (aged 55-65 and 67 or more). in acute road traffic (Road) and speech noise (Speech) played back at 66 dBA L_{eq}. AttErr = errors in an attention task (search and memory task), AttSp = speed in the attention task, WComp = performance in a word comprehension task.

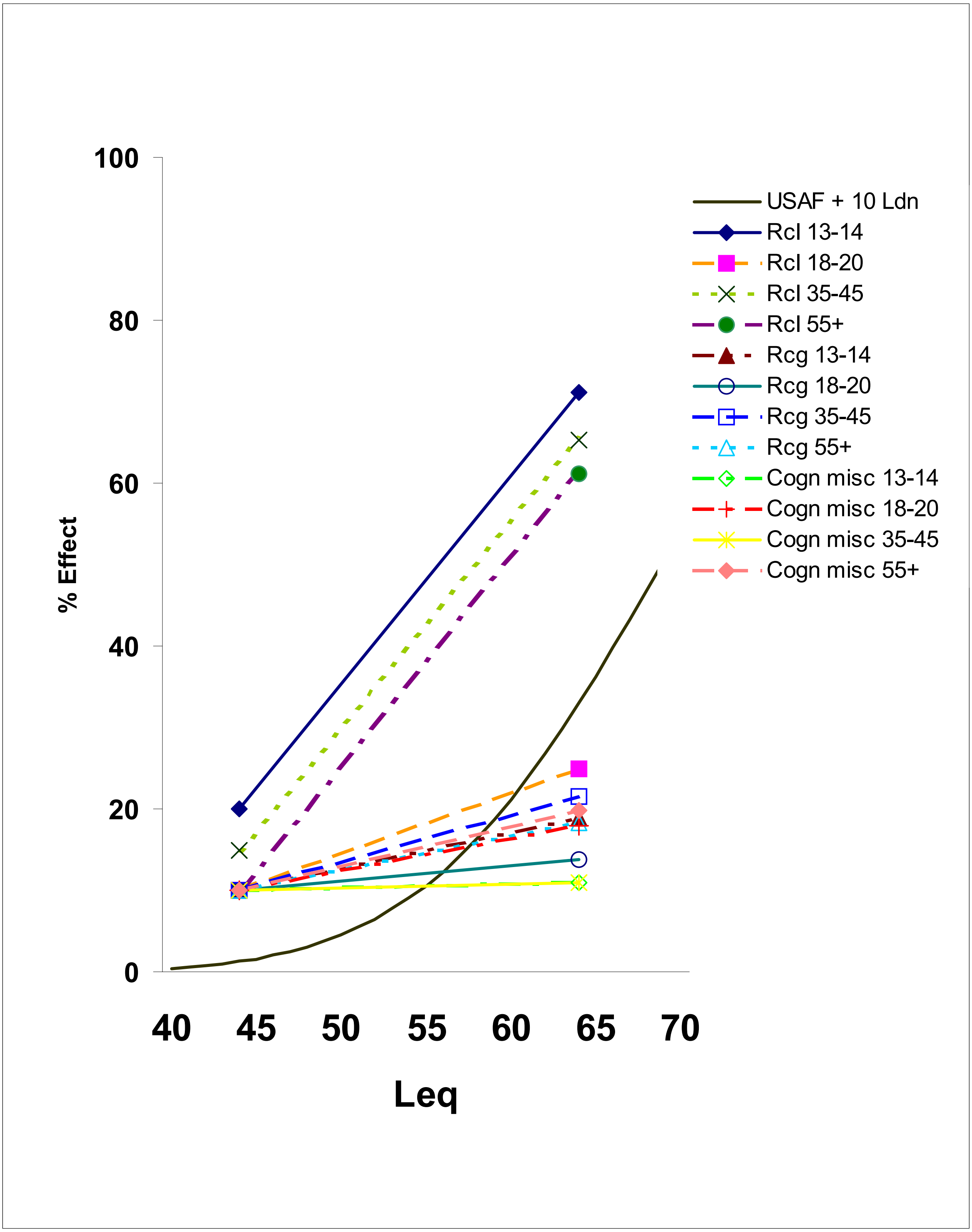

Figure 8 Summary of results presented in Figures 2-7. Rcl = recall of a text, Rcg = recognition of a text, Cogn misc = average of different other cognitive tasks, i.e. the attention task and the word comprehension task.