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Enhancing Cognitive Performances of Individuals with Intellectual Disabilities: A Human Factors Approach

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1. Introduction

Individuals with intellectual and developmental disabilities face many challenges in educational and work settings. Those with identifiable syndromes such as Down syndrome, Fragile X syndrome, and Prader-Willi syndrome manifest well established patterns of cognitive and perceptual functioning that compromise their ability to process information in the same manner or as efficiently as those without developmental disabilities (e.g., Kundert, 2008; Schwarte, 2008; Visu-Petra et al., 2007). Likewise, those with unknown etiologies of intellectual disability have difficulty remembering information or being able to focus attention in ways best suited to a task. The goal for those interested in cognitive interventions for those with intellectual disabilities is to devise techniques for establishing skills that are compromised or to enhance the efficiency of cognitive processing so tasks can be completed more rapidly. Much cognitive research on attention and memory functioning in individuals without developmental disabilities has established the basic principles by which human cognitive processing occurs. This work in the fields of perception and cognition has been put to good use in applied contexts to maximize performances. Some simple examples include designing airplane cockpits to minimize pilot error and increase efficiency (e.g., Thomas & Rantanen, 2006), proper administration of police lineups to identify criminals (e.g., Carlson, C. A., Gronlund, S. D., & Clark, S. E. 2008), and understanding the impact of distractions during driving (e.g., Strayer & Drews, 2007). Each of these areas has seen the application of basic research in cognition to the solution, or betterment, of an applied problem.

The current chapter describes a program of research that has used this philosophy of science and extended it to the study of learning and communication problems in those with intellectual disabilities. This research program has included two basic steps. The first is determining whether those with intellectual disabilities perform qualitatively similarly to or differently from those without intellectual disabilities on cognitive tasks involving visual selective attention and memory. Secondly, once the similarities and differences in cognitive and perceptual processing are known across these populations, that knowledge is utilized to design visual displays or presentation formats that maximize the performances of individuals with intellectual disabilities. Thus, the program has included studies of basic cognition and steps toward applying this basic science in meaningful contexts (e.g., design

of communication aids). This "front-end" design approach has significant advantages compared to earlier attempts at cognitive-based interventions because the responsibility for enhancing performance rests with the researcher or task design specialist rather than attempting to alter the cognitive functioning of the person with the disability. This contrasts with many early attempts at cognitive intervention for individuals with intellectual disabilities. This chapter will begin with a review of research in cognition that has informed this work and description of several early attempts at cognitive intervention for those with intellectual disabilities. These will serve as contrast for the remainder of the chapter, which focuses on the human factors approach to cognitive intervention.

2. Historical precursors

2.1 Memory research

The systematic investigation of short- and long-term memory abilities in those with intellectual disabilities began in the late 1960s. One of the main principles derived from this early work was the belief that individuals with intellectual disabilities do more poorly on most long-term memory tests because they fail to use strategies effectively. Belmont and Butterfield (1971) published an influential paper in which they described differences between individuals with intellectual disabilities and chronological age matched peers on a serial learning task. They outlined three key findings regarding differences between those with intellectual disability and those without a disability. First, those with intellectual disabilities did demonstrate significant recency effects in memory, as did those without disabilities. The differences in accuracy of recall between those with and without disabilities were due to differences between the groups for items presented early in the learning sequence. Memory for items in the first half of the lists was poorer in those with an intellectual disability. Second, Belmont and Butterfield attributed this to their finding that those with intellectual disability did not use an effective memory strategy. Specifically, they attributed the deficit to a failure to use a rehearsal strategy that would allow them to more effectively retain information from earlier in the list. Finally, they showed that when individuals with intellectual disability were instructed to use a rehearsal strategy, their memory performances improved significantly, though still not to the level of those without intellectual disability. These became guiding principles in the field for many years.

Bray and Turner (1986) termed the failure to use strategies the "rehearsal deficit hypothesis" and described its broad impact on memory functioning in those with intellectual disabilities. Individuals with intellectual disabilities can employ strategies fairly effectively but often do not do so unless direct instruction is provided. Further, those with intellectual disabilities do not tend to generalize strategies from the trained context to novel applications or to alternative presentation formats (Borkowski, 1985). Much research during this time period focused on these strategy production difficulties in those with intellectual disabilities. Reports became widespread that individuals with intellectual disability did well on implicit memory tests but poorly on effortful memory tasks (e.g., Ellis, Woodley-Zanthos, & Dulaney, 1989; Meador & Ellis, 1987), presumably because the latter was more greatly affected by strategy production and usage. Others (e.g., Borkowski, 1985) emphasized the role of metacognition in the production deficits typically seen in research on explicit memory in those with disabilities. Gutowski and Checile (1987) applied cognitive modeling methodologies to the study of memory functioning in those with intellectual disability and found that short-term storage explained more of the variance in memory scores than did

encoding or retrieval, though those with intellectual disability did not demonstrate typical levels of performance for the latter processes either. All of this work focused on the cognitive limitations of those with intellectual disabilities and on developing methods for training those limited skills to achieve enhanced performance. Little attention was given to the effect of task structure on performance.

An exception to this person-centered approach was the work of Cohen and Bean (1983) on encoding task structure and its effect on memory in those with intellectual disabilities. Cohen and Bean addressed the strategy production problem by using subject-performed tasks as a learning methodology. They had participants learn word lists and perform actions (e.g., point at the door, break the toothpick). After hearing a word list or performing a series of actions, the participants were asked to recall the words or actions performed. Results showed that differences between the groups with and without intellectual disability were reduced by more than 50% in the task performance condition relative to the word learning condition. Cohen and Bean proposed that this was due to the fact that task performance provided effective cues for memory, without the need for effortful processing. The task of performing actions induced cognitive processing that enhanced memory. The burdens of teaching, spontaneously producing, and generalizing strategies was removed. This was an early instantiation of the approach we propose in this chapter. Rather than placing the responsibility for strategy production and usage on the individual with the intellectual disability, the responsibility for constructing and designing learning tasks that naturally induce memory enhancing cognitive processing is placed on the experimenter.

Bray et al. (1998) provided a more recent example of this philosophical shift from a focus on strategy training to that of cognitive task design. These authors discussed the need for "situational supports." In their simplest form, such situational supports included access to manipulatives that could be used for memory enhancement. Fletcher and Bray (1995) provided perhaps the best example of situational supports and their promise for improving performance in those with intellectual disability. An apparatus was constructed that allowed participants to move and arrange objects and a character as a story was being read. Effective use of the manipulatives during story presentation was the best predictor of memory performance in those with and without intellectual disability. This work demonstrated the memory potential of those with intellectual disability and reinforced the effectiveness of the task design approach. Individuals with intellectual disability have the potential for quality memory performance but require more task, or external, support than do those without intellectual disability.

2.2 Research on visual selective attention

The combined abilities to focus on task-relevant information and inhibit attention to irrelevant information in a visual array comprise the skills of visual selective attention. This aspect of visual attention has perhaps been the most widely studied in cognitive psychology over the past 30 years. The seminal works of Anne Triesman (Treisman, 1998; Treisman & Gelade, 1980), Jeremy Wolfe (e.g., Wolfe, 1994, Wolfe et al., 2011) and many others (e.g., Duncan & Humphries, 1995, Tsal, Meiran, & Lamy, 1995) have led to significant advances in theory development and understanding of human attentional functioning. As importantly, these investigators have defined standard methodologies by which human visual search performance can be studied systematically. In a typical visual search experiment, series of visual arrays are presented with a single target embedded in a surround of varying numbers

of distracters. Time to determine whether the target is present or absent is recorded. A key performance measure is the average increase in reaction time as the number of elements in the array increases. If target detection time increases as more distracters are added, this is evidence of serial search. Presumably items are searched in succession until the target is identified. If, on the other hand, the target can be identified equally rapidly regardless of the number of distracter stimuli present, this is evidence of parallel search. In parallel search it is assumed that the target is so salient that it is immediately attended to ("pops out") when the array is presented. Examples of visual search tasks discussed in this chapter are shown in Figure 1. The leftmost example is a trial from a color-based feature-search task. In feature search, the target (e.g., a black circle) is defined by a difference from the distracter(s) along a single visual dimension (e.g., color). Other dimensions (e.g., shape, size) are held constant. In conjunctive search, two types of distracter stimuli are present, and each shares one feature with the target. For example, in Figure 1, the middle array shows a trial in which the black circle target must be found among black triangles, which share color only with the target, and white circles, which share shape only with the target. This is a more difficult task than feature search due to the featural overlap of all distracters with critical characteristics of the target. Finally, the guided search task includes one set of distracters that share a feature with the target and a second class of distracters that share no critical features with the target. Attention to the latter should be inhibited if the visual selective attention system is functioning efficiently.
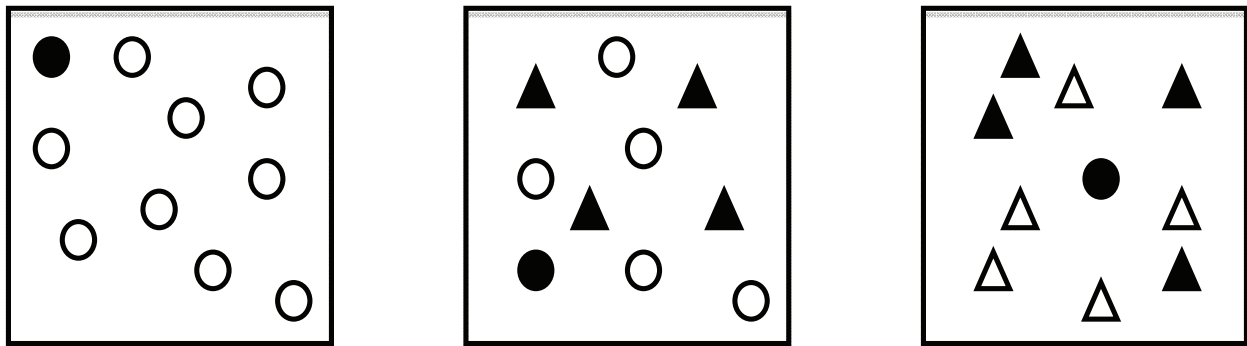

Fig. 1. Example visual search arrays. The left array is an example of Feature Search, the middle is an example of Conjunctive Search, and the right array is an example of Guided Search. The black circle is the target in each array.

Understanding visual search in individuals with intellectual disability is an important goal for intervention. In many learning contexts, establishing attention to the critical elements of visual arrays and reducing attention to distraction iare critical goals for intervention success. Merrill and O'Dekirk (1994) concluded from a study of visual selective attention in those with Down syndrome and other etiologies of intellectual disability that those with a disability were slower in general and less likely to use top-down processing to increase the efficiency of visual search. Top-down processing involves using information about target identity to increase the efficiency of search. For example, if you know you are looking for a black circle (as in the Figure above), you theoretically can focus attention on the black elements in the visual array and inhibit attention to the non-black elements. This in effect would reduce the number of elements that must be considered, and therefore reduce target detection times. If unable to do this efficiently, target detection times would be significantly longer, as was found by Merrill and O'Dekirk. This inability to inhibit processing has been noted as a potential core deficit in those with intellectual disabilities (Dempster, 1991).

An important historical precursor to the human factors approach described herein was the work of Herman Spitz on visual search in those with intellectual disabilities (e.g., Spitz, 1969; Spitz & Borland, 1971). Spitz focused on what he termed "input organization" (Spitz, 1966) as a critical factor for increasing the efficiency of visual search, and visual attentional functioning in general, in those with intellectual disabilities. Much as proposed in the human factors approach, Spitz described the effects of re-structuring visual arrays on cognitive performances. He demonstrated in many studies how reducing the informational complexity of presented information could result in the reduction of differences between those with and without intellectual disability. Unfortunately, this work did not receive the attention it merited and was not pursued more broadly in the field.

This section has focused on the historical precursors that shaped our thinking and selection of methodologies for the pursuit of demonstrating how task design can be used to facilitate the performances of individuals with intellectual disabilities. Some of the work in basic cognitive science established general principles of long-term memory functioning and visual selective attention in those without developmental disabilities as a foundation for comparison for our work. Other work cited, particularly that on early theories of memory deficits in those with intellectual disabilities, will serve as contrast to the promise of the human factors approach for enhancing cognitive performances and learning in those with disabilities.

3. The human factors approach

This section will describe the work done to establish the human factors approach as a particularly effective means for improving the cognitive functioning of those with intellectual disabilities. Again, this approach contrasts sharply with that taken earlier in the field in which strategy training was commonly pursued unsuccessfully. Rather, as Cohen and Bean (1983) emphasized, the responsibility for enhancing performance should be on the experimenter/teacher who is designing the learning context. Rather than trying to change the learner, the onus is on the experimenter/teacher to structure the task so that effective cognitive processing will occur spontaneously in response to that task structure. In the example of airplane cockpit design, for example, the human factors approach would dictate that the structure of the controls in terms of positioning, visual features, etc. be altered rather than training the pilots to use the existing controls more effectively. As we will show, knowledge of established principles of human memory and visual selective attention can be applied toward the goal of enhancing performances of individuals with significant intellectual disabilities.

3.1 Enhancing memory performances in those with intellectual disabilities

The work described herein on enhancing memory in those with intellectual disability derived primarily from memory research on the generation effect. The generation effect refers to the finding that memory for self-generated information is better than is memory for provided information. The effect has been demonstrated experimentally and in applied contexts (e.g., McNamara, 1995; Slamecka & Graf, 1978). Soraci et al. (1999) demonstrated important cueing principles involved in the generation effect, and that provide the theoretical basis for the memory work described below. The five basic cueing conditions employed by Soraci et al. are shown in the Table below. There were two types of cues, congruous and incongruous. Congruous cues defined the solution for the word fragment completion task. Importantly, the word

Condition	Fragment	Cue(s) Provided
Congruous One Cue	C__P	A hat
Congruous Two Cues	C__P	A hat; A head covering
Congruous Two Referents	C__P	A hat; A bottle top
Incongruous One Cue	C__P	NOT a hat
Incongruous Two Cues	C__P	NOT a hat; NOT a policeman

Table 1. Cueing conditions used by Soraci et al. (1999) in their study of generative processing and memory enhancement

fragments used had multiple possible solutions. The congruous cues determined the proper solution from the alternatives. In the first example in Table 1, the word fragment C__P could be completed by CAP, COP, or CUP. The cue provided determines that the correct completion is CAP. The other congruous cueing conditions provide two cues for the correct solution. The distinction between these cueing conditions is that one provides two definitions for a single referent and the two-referents congruous cueing condition provides two cues for alternative definitions of the solution. This is a critical distinction for memory because the two referents provide two potential retrieval routes for the to-be-remembered solution. The incongruous cueing conditions provided negating cues, which ruled out one or more of the possible word fragment completions. As seem in the first example of incongruous cueing in Table 1, the solution CAP is ruled out by the cue "NOT a hat" and therefore either COP or CUP would be correct. For the two-cue incongruous condition both CAP and COP are negated, leaving only CUP as a proper solution. The incongruous two-cue condition provides two potential retrieval routes for the solution, similarly to the two-referents congruous condition. These generative encoding conditions were compared to identical cueing conditions but for which the complete words were provided, a non-generative learning environment. Results across a series of five experiments clearly showed an advantage for the dual-referent learning conditions, particularly in generative learning contexts. This research demonstrated how altering the manner in which information is presented at encoding can affect recall, and did so via application of established principles of human memory. This approach formed the foundation for our subsequent research involving participants with intellectual disabilities.

The generalization of this work to those with intellectual disability required that a move be made away from verbal materials to visual materials (Carlin et al., 2001). We did this because we wanted to develop methods that would be applicable to the majority of individuals with intellectual disabilities, who often have limited verbal skills. We also wanted this work to inform the design of visual supports for those with intellectual disability. The challenge became one of developing visual analogs of the cueing conditions used by Soraci et al. (1999). We also wanted to adhere to the human factors concept of placing the burden for inducing cognitive processes that produce better memory on the task designer rather than teaching new strategies to our participants. The presentation format used in the first demonstration of these principles with those with intellectual disabilities was a picture blurring methodology. A set of pictures was presented to each participant with half in each of two formats. Half of the pictures were presented clearly initially and slowly faded out of focus over a period of a few seconds. The other half of the pictures were initially blurry and slowly faded into focus over the same period of time. The prediction was that the fade-in presentation format would result in better memory for the pictures because it induced cognitive processing consistent with memory enhancement. During the fade-in sequence we surmised that participants would be trying to guess the proper label for the

picture. Initially these guesses were very likely to be incorrect, but eventually the correct solution would be reached. In effect, the participants were generating multiple incongruous cues for later recall. This is directly analogous to the incongruous two-cue condition from Soraci et al. The fade-out condition, however, also had reason to enhance memory moreso than the fade-in condition. In the fade-out condition participants were able to identify the picture immediately and therefore had more time for rehearsal.

Results from this study were consistent with the former prediction; recall of pictures was greater if they were faded in than if they were faded out. The opportunity to make incorrect guesses prior to arriving at the final solution resulted in better memory than did more time for rehearsal. Presumably, the generation of multiple retrieval routes (i.e., incorrect guesses) during encoding and the experience of arriving at the correct solution after a period of uncertainty (i.e., the "aha" effect, Auble, Franks, & Soraci, 1979; Topolinski & Reber, 2010) led to enhanced long-term recall. Interestingly, this finding held for those with intellectual disabilities and chronological age matched peers, but not for mental age matched peers. The mental age matched group had a mean age of just seven years. It was believed that the lack of a generative encoding advantage in this younger group was due to their less well-developed semantic network, which resulted in a lower rate of cue generation during the fade-in sequence.

To address this issue further, Carlin et al. (2005) employed a methodology that removed the requirement that the potential solutions be internally self-generated. This study employed the flicker methodology commonly used for the study of basic visual processing (e.g., Rensink, O'Regan, & Clarke, 2000). In this task a participant is required to identify an object that is changing in a flickering scene. The visual presentation involves alternating presentation of pictures of the same scene but with one object altered. Typically the object would be changed in color, size, shape, or its presence/absence. The brief blank period (i.e., flicker) between presentations of the two variations of the scene interrupts attention and makes identification of the change more difficult. Without the brief interruption changes are immediately identifiable. The flicker task is completed by successively attending to objects that may be changing. Attention must be maintained across the flicker period so that the two versions of the object can be compared. In effect, a participant is attending to objects and ruling them out until the correct object is identified. This again is analogous to the incongruous cueing used by Soraci et al. (1999). During the flickering presentation, participants select objects in the scene successively until the correct one is identified. For each incorrect object selected, the participant attends then concludes, "It is not the ____." These attended objects, which are eventually negated, can serve as retrieval cues at test. In addition, the identification of the correct solution after a period of uncertainty results in a feeling of insight and resolution, the "Aha" effect. Thus, despite this shift in methodology from fading to flicker, the underlying cognitive processes induced are quite similar and conducive for enhancing memory. One advantage of this flicker methodology over the fading technique, however, is that the memory cues are external; they are objects in the scene. Because they do not have to be self-generated as in the fading manipulation, we believed the flicker methodology would be applicable to individuals of younger ages.

As in the previous study, performances of those with intellectual disabilities were compared to groups matched for mental age and chronological age, respectively. All participants were presented with 16 flicker trials and 16 trials without the flicker so that changes could be identified immediately. The no-flicker condition served as a no-cue comparison to the flicker

condition in which incorrect alternatives were considered prior to final solution. Results showed firstly that time needed to identify the changing objects in the flicker condition varied across groups. The chronological age matched group identified changes more quickly than did the other two groups. In terms of memory performance all three groups demonstrated recall advantages for the changes from the flicker condition. The generative encoding context again resulted in better memory, and in this case, this was true for the mental age matched group as well. The percentage gains in the generative encoding contexts for the fading and flicker methodologies are shown in Table 2. The gains are quite substantial and consistent across these two studies. A critical difference, however, is the effectiveness of the flicker methodology for the mental age matched group, which did not benefit from the fading technique.

Presentation Mode	Group		
	Intellectual Disability	Mental Age	Chronological Age
Fading	25%	-7%	24%
Flicker	18%	22%	19%

Table 2. Percentage memory gains for the generative presentation encoding conditions relative to the respective control conditions.

These two studies of the application of the human factors approach to memory intervention in those with intellectual disability demonstrate the promise of such an undertaking. The strong foundation in principles of cognitive science on memory and the removal of the need for direct instruction are strengths of this approach. The participants were not told to generate potential retrieval cues during learning, but did so in response to the presentation modes employed. This is a significant advantage over the earlier attempts at strategy training with those with intellectual disabilities. These types of presentation formats also are quite applicable to computer-based learning formats used in many classrooms today. The learning tasks (i.e., fading and flicker) are game-like, easily programmable, and the participants seem to enjoy the challenge involved in the tasks. Taking this step into the classroom is the next challenge for this program of research.

3.2 Reducing false memories in those with intellectual disabilities

These studies on memory enhancement focused on accuracy of recall of learned materials. An important aspect of memory to consider, however, is that of false memory generation. The study of false memories has been a major focus over the past 20 years in cognitive psychology. The standard methodology used in studies of false memory is the DRM paradigm developed from the work of Deese (1959) and Roediger and McDermott (1995). In this methodology lists of related words are presented for later remembering. The words all relate to a single "critical" item, which is assumed to be activated internally via the process of spreading activation (Collins & Loftus, 1975). At test, the participant must differentiate words presented during acquisition from those internally activated via spreading activation. Approximately half of the time participants report having seen (or heard) the critical item during acquisition even though they actually did not. One of the more widely accepted explanations for these types of false memories is the activation-monitoring framework (Roediger, et al., 2001). The false reports are hypothesized to result from the combined processes of spreading activation during the acquisition phase and source monitoring errors

during the test. The source monitoring errors result from confusion regarding whether items were externally experienced or internally activated only.

Several studies have investigated the effects of encoding manipulations that enhance veridical memory on false memory. Toglia, Neuschatz, and Goodwin (1999) investigated the effects of levels of processing manipulations on true and false memory in participants without intellectual disabilities. They found that manipulations that increased memory for experienced items also increased false memory rates. They termed this the "more is less" effect. Encoding manipulations that increase memory have the negative effect of increasing false memories. The net effect is a decrease in the overall accuracy rate. Soraci et al. (2003) assessed the influence of generative encoding contexts on false memory. These investigators found that generative encoding increased memory for old items without the concomitant increase in false memories. This pattern was referred to as the "generation at no cost" pattern. These results also provided support for the promise of using generative encoding manipulations to augment the memory performances of individuals with intellectual disabilities without an associated increase in false memories.

Carlin et al. (2008) extended this work on false memory and generative encoding to individuals with intellectual disabilities. A group of individuals with intellectual disability was compared to groups matched for mental age and chronological age. Items were pictures representing lists of related items as typically is done in the DRM paradigm. Pictures were presented in static form or fading in as was done by Carlin et al. (2001). The test comprised a series of questions regarding the presence or absence of items. Participants were asked "Did you see a _____?" for each item. This form of testing was done to reduce ceiling effects present when simple pictorial visual recognition testing was employed. We also wanted a test format that mapped more directly to typical questioning formats used educational and forensic settings. The recognition test included old items (i.e., experienced during acquisition), critical items, and unrelated foils.

Those matched for chronological age did significantly better than the other two groups for measures of veridical and false memory. Critical comparisons between those with intellectual disability and mental age matched peers are shown in Figure 2. The left portion of Figure 2 shows that those with an intellectual disability had significantly higher false alarm rates for unrelated foils. This is consistent with the common report of acquiescent response bias in this population (e.g., Finlay & Lyons, 2002). These rates of false reports for unrelated items were subtracted from the rates for old and critical items in the right portion of Figure 2. Once this correction was made differences in false memory rates were no longer significant. However, the group with intellectual disability had a significantly lower accuracy rate for old items. This finding of decreased accuracy in those with intellectual disability was reinforced in a series of signal-detection analyses.

These results demonstrate several important aspects of memory functioning in those with intellectual disabilities. First, the similar patterns of veridical and false reports across groups indicate that those with intellectual disabilities show effects due to spreading activation as do those without disabilities. Thus, there does not seem to be a qualitative difference between the memory processing of these groups. Second, those with intellectual disabilities did perform lower in memory accuracy, primarily due to differences in memory rates for old items. Thus there is need for memory support in this population. The fading technique, which was shown to be effective for enhancing memory in earlier work (Carlin et al., 2001)
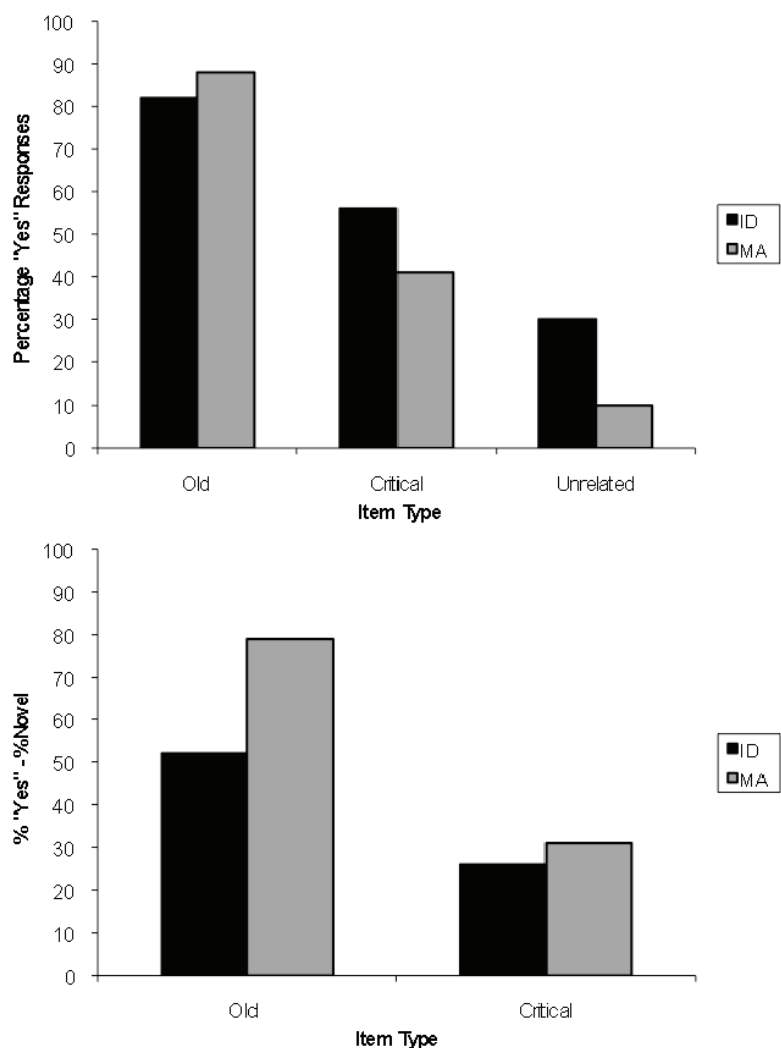
Fig. 2. Percentage affirmative reports for old, critical, and unrelated items for participants with and without intellectual disabilities.

was not effective in this context. The lack of effect is likely due to the change in method of testing. The generative encoding technique of fading was effective for a test of free recall but not for the cued recognition test employed in this study. This was not unexpected given the more consistent mapping between generative encoding contexts and generative test conditions (i.e., free recall) than between the acquisition and test conditions used in this study. This is in line with the cognitive principles of transfer-appropriate processing (Morris, Bransford, & Franks, 1977) and encoding specificity (Tulving & Thompson, 1973). Finally, the results showed the role of response bias in memory measurement in those with intellectual disabilities. Steps must be taken not only to control this bias experimentally or statistically, but also to identify presentation and test formats that may minimize these effects.

In a step toward this goal, we recently completed a study assessing the impact of several presentation formats on veridical and false memory in those with intellectual disability. This study compared the performances of children and adolescents with and without intellectual disability on a DRM false memory task. Participants completed the task under

three different presentation conditions, visual, auditory, and both visual and auditory. The visual condition comprised presentation of pictures for related lists. The auditory condition included a series of verbal labels only. The audio-visual condition included presentation of pictures with accompanying verbal labels. Items were balanced across these conditions and populations. The test was identical to the cued recognition test described above (Carlin et al. 2008). The only change to the test was the addition of a fourth class of item, related foils. Related foils were alternative items from the lists presented at acquisition. Thus, three levels of foil were used with each receiving a different level of activation during encoding. Critical foils likely were activated repeatedly during the acquisition phase. Related foils may have been activated to some degree due to relatedness to some or all of the presented items, but not to the same degree or with the same frequency as the critical foils. The unrelated foils were likely not activated during acquisition. Inclusion of all three foil types allowed us to delve more deeply into the nature of memory errors in those with intellectual disability.
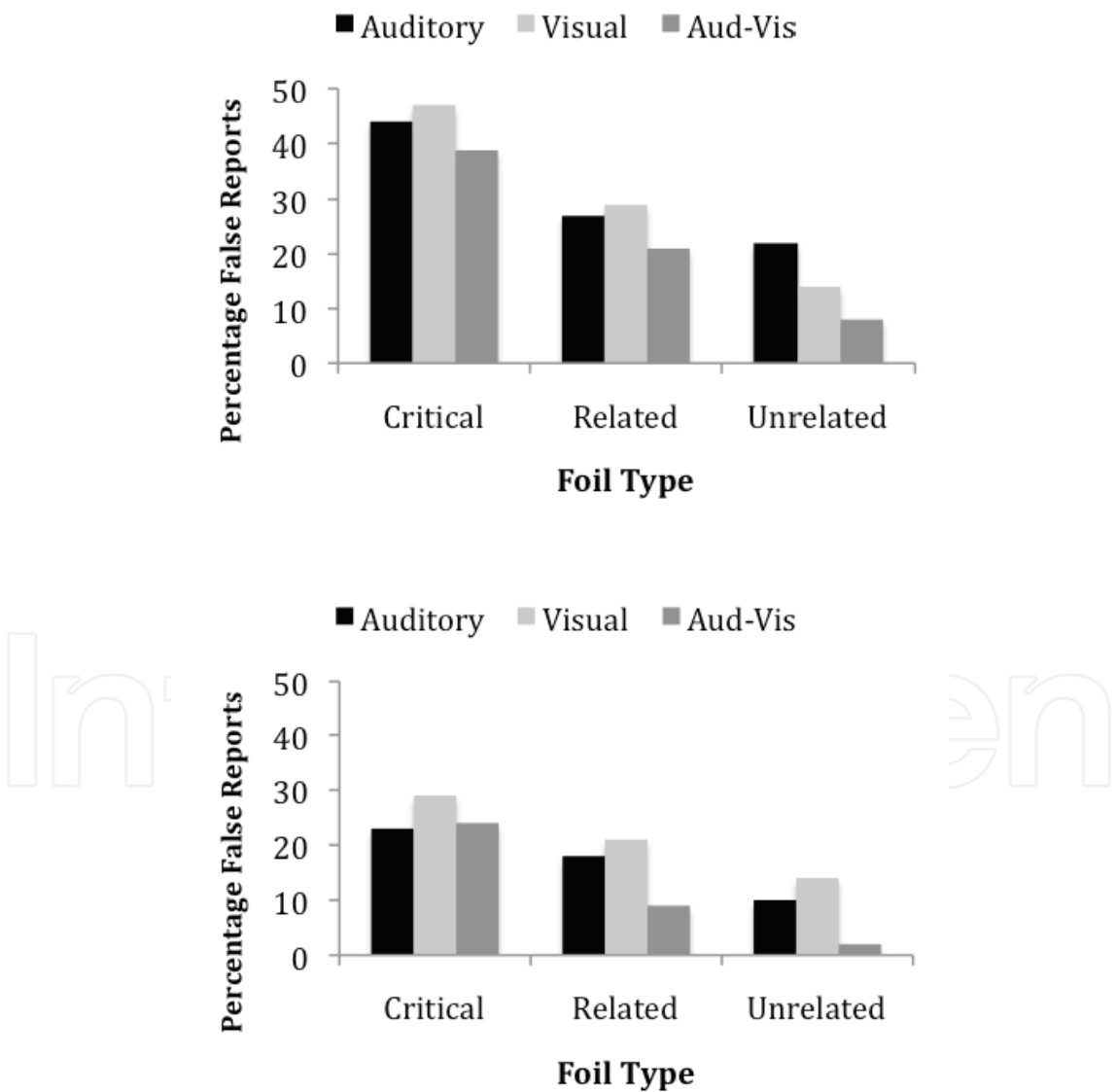

Fig. 3. False report rates for those with intellectual disabilities (left) and their mental age matched peers (right).

Results showed that presentation condition had a significant impact on memory for items presented at acquisition. For each group, recognition rates were highest for the audio-visual condition, second highest for the visual-only condition, and lowest for the auditory-only condition. Relative to the auditory-only condition, percentage gains in memory for the visual (20%) and audio-visual (36%) conditions were quite large. However, more encouraging news emerged from the analysis of false reports across the three foil types. False report rates for the participants with intellectual disability (left panel) and for the mental age matches (right panel) are shown in Figure 3. As can be seen, the rate of false reporting in the auditory-visual condition was significantly lower than that in either of the single-modality encoding conditions. This was true for both groups of participants. When combined with the data for accuracy in responding to previously encountered items, it is clear that memory accuracy in terms of both veridical and false memory is enhanced in the auditory-visual condition.

These data attest to the powerful influence of simple manipulations of visual structure on core cognitive processing in individuals with intellectual disabilities. Significant improvements in memory were evident simply by restructuring the nature of the encoding context. This was true in terms of increasing accuracy of reporting the presence of old items and for reducing the prevalence of false reports. These techniques represent the application of established principles of memory functioning to the benefit of those with intellectual disabilities. That these techniques require no special instruction, complex programming, or machinery makes them particularly amenable to classroom and workplace intervention.

3.3 Visual selective attention

The focus of much human factors work is on how design variables affect visual processing and scanning of visual arrays. We have undertaken a program of research intended to better understand the visual selective attention strengths and weaknesses of those with intellectual disabilities. The goal of this program of research is to apply this knowledge to the design of visual supports that guide attention to critical components of arrays and minimize attention to irrelevant elements so that communication and knowledge acquisition can be hastened in these populations.

Carlin et al. (1995) published the first paper on visual search in individuals with intellectual disabilities using the standard methodologies and principles established by Treisman and Gelade (1980). The Carlin et al. study of the visual search efficiency of those with intellectual disabilities compared how the visual dimension for search affected performance. Target detection times for the dimensions of color, form, and size were compared across groups with and without intellectual disability. In this case, the comparison group comprised college students. The main purpose was to determine how increasing distraction in the arrays (i.e., increasing the number of distracters) would influence search efficiency. For relatively simple visual arrays it is not uncommon to find that target detection time does not increase even when the number of distracters increases (known as parallel search). It is presumed that the target is so easily distinguishable from distracters that it can be detected almost immediately regardless of the number of non-targets in the array. However, if the visual search system is not functioning efficiently or if the discriminations between targets and distracters become more difficult (i.e., target-distracter disparity is reduced), then target detection times tend to increase as the number of distracters increases (i.e., serial search).

This study compared performances of those with and with intellectual disabilities on relatively simple, visual search tasks with targets and distracters that were highly discriminable for those without disabilities. Example arrays are shown below.
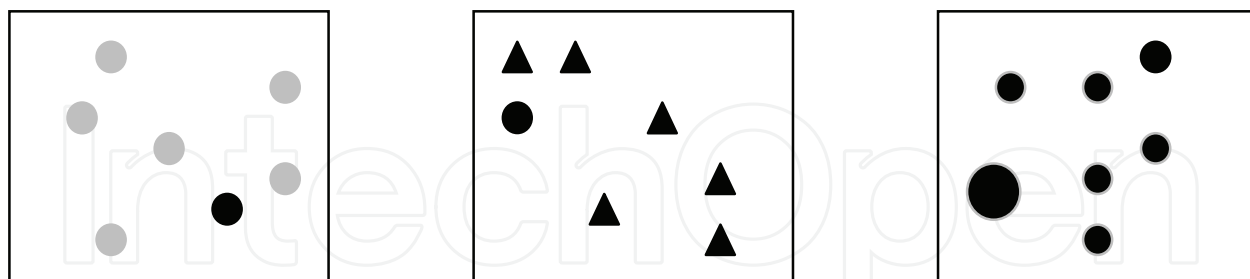

Fig. 4. Example visual search arrays: color-based search (left), form-based search (middle), size-based search (right).

Results from this initial study clearly demonstrated that there were significant, and quite large, differences between the groups. Those with intellectual disability were very much slower overall to respond. In fact, response times for those with intellectual disability were approximately twice as long as those for participants without an intellectual disability. In addition, response times were differentially affected in the two groups by increases in numbers of distracters. For those without a disability, response times were equivalent at all set sizes, indicating parallel search was being performed. In those with an intellectual disability response times indicated parallel search for the color dimension but serial search for the dimensions of form and size. This shows that discriminability of features along those dimensions likely is compromised in those with a disability. Given the magnitude of differences seen in this study, we investigated further to determine whether the large differences in search times could be reduced with extended practice. In an unpublished follow-up study, we found that the magnitude of the group main effect could be reduced by approximately 50% with extended practice performing the visual search task. Thus, Carlin et al. (1995) likely overestimated the magnitude of the group difference. This knowledge has been applied to all of our subsequent work, however. We now train participants until their performance reaches asymptote on simple search tasks prior to beginning the formal experimentation.

In addition to the simple training follow-up, we continued to investigate how modifications to the structure of visual search arrays could impact search efficiency in those with intellectual disabilities. Carlin et al. (2002) designed a methodology for determining the roles of top-down and bottom-up processing in search in those with an intellectual disability. Top-down processing in the context of visual search mainly refers to the participant's ability to use prior knowledge of the target to facilitate detection. For example, if given the target "black circle", one could use this knowledge to parse the array by color prior to searching more consciously through all elements of that color. That is, one could focus attention on the black elements in the array and inhibit attention to all non-black elements. This would effectively decrease the number of objects needed to search to find the target, and therefore greatly reduce detection times. Example arrays similar to those used by Carlin et al. (2002) are shown in Figure 5 below. The target in each of these arrays is the black circle. In the leftmost array, you can see that search could

involve four elements or only three if search could be limited to the black elements only. Thus, color could be used to "guide" or limit attentive search to a subset of all elements in the array. The same principle holds true for the other two arrays as well despite the increase in total number of array elements. In the experiment, the number of black elements varied from two to four and the numbers of distracters varied from four to sixteen. This enabled us to determine the exact nature of search and the role of top-down processing across a broad range of visual presentation formats.

Fig. 5. Example guided-search arrays. The target is the black circle. Number of search-relevant stimuli (i.e., black) is held constant while total number of distracters increases from left to right.

The results (see Figure 6) showed that those with intellectual disabilities were able to use knowledge of the target's physica
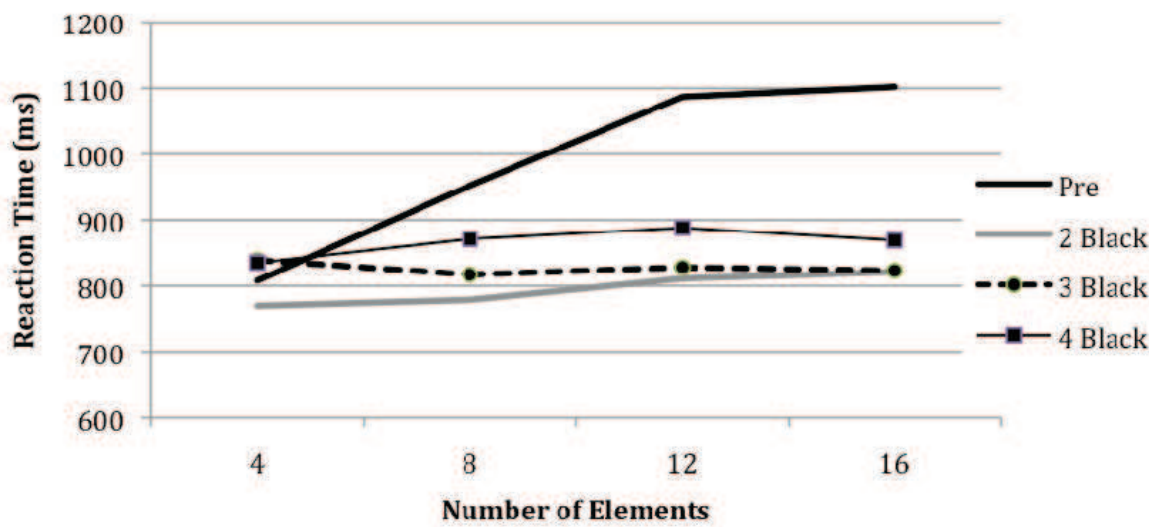

Fig. 6. Target identification times by total number of elements in the array and number of target color (Black) elements.

characteristics to increase the efficiency of search. The black line in the Figure shows search times on a feature search pre-assessment in which a black circle was embedded in an array of otherwise black squares. This function shows that effortful search was required; search times increased rapidly as the number of distracters increased. More significantly, however, is the pattern of search times for the guided trials. Search times did not increase as set size increased, indicating that in fact attention to non-black elements in the arrays was limited. The increase in search time as the number of black elements increased showed that search

was limited to the black elements but proceeded in a serial fashion. Search times increased as a function of the number of black elements but not as a function of the total number of elements in the array. These data provided strong evidence that those with intellectual disabilities could engage in fairly sophisticated, top-down guided, visual search behaviors, and that group differences in visual search likely were quantitative rather than indicative of qualitative differences in processing.

We continued this line of inquiry by investigating an even more sophisticated mode of visual search. Carlin, Chrysler, and Sullivan (2007) assessed conjunctive visual search performances of those with intellectual disability and their mental and chronological age matched peers. Conjunctive search tasks are more difficult than feature or guided search tasks (see Figure 1 above) because in conjunctive search the target is defined by characteristics along two dimensions (e.g., color and form). For example, in Figure 1 (middle), the black circle target is embedded among black triangles, which share the color feature, and white circles, which share the shape feature. Thus, featural overlap between the target and the surrounding distracters is much greater in the conjunctive search task than in the guided or feature search tasks.

Results of this experiment showed striking similarity between the search times of those with intellectual disabilities and their mental age matched peers. Not only were overall target detection times similar, but the patterns of performance across the different search tasks were very similar. These groups demonstrated efficient search for the color feature, form feature, and guided search tasks. The average increase in search time per additional distracter in each array was less than 5 ms. For the conjunctive search task the average increase per additional distracter was much greater, approximately 20 ms per additional item. These data showed that those with intellectual disabilities perform very similarly to individuals matched for mental age. This is consistent with a developmental explanation for the search discrepancies identified in early work. The chronological age matched group in this experiment also showed efficient search on all tasks except the conjunctive search task. However, the increase per item in this group was much less (9 ms per item) than that in the other groups. In addition, the response times for this group were approximately half those of the other two groups.

This series of investigations of visual search performances in those with intellectual disabilities has shown that the performances of these individuals are governed by the same principles as those of individuals without disabilities. Visual search times are affected by variables such as target-distracter disparity along a single dimension and featural overlap, and performances of those with intellectual disabilities are very similar to those of mental age matched comparisons, though much worse than performances of chronological age matched peers. That differences are purely quantitative in nature rather than qualitative provides great promise for the application of basic cognitive science to the design of interventions for those with disabilities. The vast literature on visual search in humans, performed almost entirely on individuals without disabilities, should generalize well to the performances of those with disabilities. The promise of such intervention science would have been much more bleak had those with intellectual disabilities not been governed by these same cognitive principles.

Along with these investigations using the classic visual search methodology, we have continued another avenue of research on visual search using the flicker methodology

described above in the section on memory. Use of the flicker task allowed us to investigate visual search in more ecologically valid contexts, visual scenes. Again, the basic task in a flicker experiment is to identify the object that is changing in the scene. A systematic search of the scene must be undertaken to complete the task most efficiently. Carlin et al. (2003) used this methodology to investigate search for changes defined by color, form, or presence/absence. Changes occurred either in the area of central interest in the scene (i.e., the location to which attention was initially directed) or to other peripheral areas of the scenes. A subset of the participants performed the task using an eye-tracking apparatus so that deeper understanding of scan patterns could be obtained.

All participants were able to detect the changing object in all scenes. For some scenes, detection of the changing object occurred very rapidly and in other scenes, target identification took more than a minute. Despite this variability across scenes, systematic patterns of visual scanning were identified. Those with intellectual disabilities took much more time to detect the changes than did those without an intellectual disability. This was true of both central and peripheral changes. However, there was a significant interaction of group and location indicative of pronounced delays in detection for the peripheral changes in those with a disability. Eye-tracking indices provided some insight as to the basis of this group difference. It was clear that response times once attention was directed to the target object did not differ across groups. Participants in both groups, once fixated on an object, would maintain attention across one or two flickers of the scene then respond. Rather than a response-based effect, data indicated that those with intellectual disability maintained attention in the area of central interest for a prolonged period of time before scanning other areas of the scene. Once attention was released from the area of central interest, detection occurred about as rapidly as in those without a disability. This effect could be strategically based or perceptually based. The eye-tracking and behavioral data did not allow for a firm differentiation of these hypotheses. Strategically, those with intellectual disability may require more certitude about a decision before moving to the next possibility. They may wait for more variations (or flickers) of the scene prior to responding. However, the end-of-trial decision data seem to run counter to this hypothesis. From a perceptual standpoint, we favor the hypothesis that those with intellectual disability are less sensitive to visual cues in their environment, particular peripheral cues, and therefore do not shift attention in response to these cues as rapidly. Support for this hypothesis can be found in the work of Hollingworth, Schrock, and Henderson, (2001) and Zelinsky (2001). These investigators presented evidence that detection times in flicker tasks occurred more rapidly than expected by chance, and therefore must be guided by some subtle form of visual cueing. We designed a modification of the flicker methodology to assess this hypothesis.

In this variation of the standard flicker methodology we made a slight change to the typical flicker sequence. Rather than having the flicker sequence continue indefinitely, we eliminated the brief blank period every few seconds so that the change would flash once very briefly. With the blank intervening period removed, the target object changes in full view of the participant. If this occurs while attention is directed toward the changing object, then the change is readily apparent. However, if this occurs in the periphery, it can go unnoticed or it can be detected as a slight perturbation in the periphery of the visual field. You cannot identify what changed but attention may be drawn to that area of the scene for focal processing. As in the previous study, changes occurred either centrally or in the

periphery. Some trials included the novel cueing procedure and others did not. The predictions were that cueing would decrease detection times for centrally located changes in both groups but for peripheral changes only in the group without intellectual disability. This was based on the premise that those with intellectual disability are less sensitive to these subtle cues in their peripheral visual fields. In effect, those with intellectual disabilities were predicted to have more limited functional fields of view (Mackworth, 1965; Scalf et al., 2007).

Findings were consistent with this hypothesis. There were significant decreases in change detection times when the cueing manipulation was used relative to standard flicker presentations. This was true for those with intellectual disability and for those in the mental and chronological age comparison groups. However, an interaction showed that only those with intellectual disability did not show this advantage for the peripheral changes. For those with intellectual disability the cueing enhanced performance only in the central location condition. This is consistent with our hypothesis that those with intellectual disability have a more limited functional field of view and therefore are less sensitive to subtle visual cues in the periphery. This certainly is a finding with important implications for intervention design.

4. Applications of the human factors approach

This chapter has outlined the basis for our approach to intervention design for those with intellectual disabilities in the general cognitive psychology literature and in a series of experiments performed in our laboratory. Ultimately our goal is to translate this basic cognitive science into intervention design for those with various forms of intellectual disability. In this section we describe our initial forays into the realm of application. Our main foci have been the design of visual supports to learning and the design of communication aids for those with limited verbal skills. We first describe application of this work to the design of a visually based training procedure to establish matching behavior in children and those with intellectual disability. We then describe an initial study that demonstrates the promise of this work for the design of communication boards commonly used by those with intellectual and other forms of disability.

Extension of this work to matching to sample was reported by Mackay et al. (2002). The goal was to establish two-choice matching in children not demonstrating this behavior in a pretest. Because matching can be used as a tool for teaching important relations (e.g., number-word, picture-verbal label), it is important to establish early as a prerequisite skill for higher-order learning. In this study we took what had been learned about manipulations of visual array structure to increase the probability of selecting the correct comparison on a match-to-sample task. The principle that guided the design of this intervention was that of target-surround disparity. When target-surround disparity is exaggerated, the target draws attention and therefore becomes more likely to be selected and reinforced. We attempted to increase the perceptual salience of the correct match by embedding it in a homogenous field of distracters. We believed this would make the match "pop out" of the visual array. However, the possibility was present that increasing the number of distracters in the array could actually be detrimental. Increasing the number of distracters reduces the probability of correctly selecting the match by chance.

The training developed was one in which the number of comparisons in the matching task was increased from two during the pretest to nine in the initial stages of training. That is, the matching stimulus was embedded in a surround of eight identical alternatives. If the correct match were selected, then the number of comparisons was reduced until only two comparisons remained.

Example trials are shown below in Figure 7. Participants began with a two-choice matching pretest. If unable to attain criterion performance they were presented with the training program. In the first stage of training the target was embedded in a field of distracters, which all were identical to form a homogenous surround. Once the participant correctly selected the match the number of distracters was reduced by one. This systematic reduction of distracters based on accurate responding continued until only two comparisons remained. This was the final test of the effectiveness of the training procedure. The logic of the procedure was that visual array structure could be used to guide attention to the correct comparison. Because each correct response was reinforced, we hoped the child learned the generalized matching behavior during the procedure. Note that the sample and distracters varied from trial to trial. One concern we had in the development of this procedure was that the participant could complete training successfully by responding based on oddity (i.e., pick the different one). In each choice array during training, the match was the odd stimulus. If oddity controlled behavior, performance would diminish on the final test when just two choices remained. Of the 28 participants, 75% completed the training successfully. Nearly half of these did so with very limited numbers of errors. This was consistent with the nature and purpose of the visual array manipulation of disparity. The goal was to draw attention immediately to the matching comparison so that it would be selected and reinforced without the need for trial-and-error learning during the early stages of training.
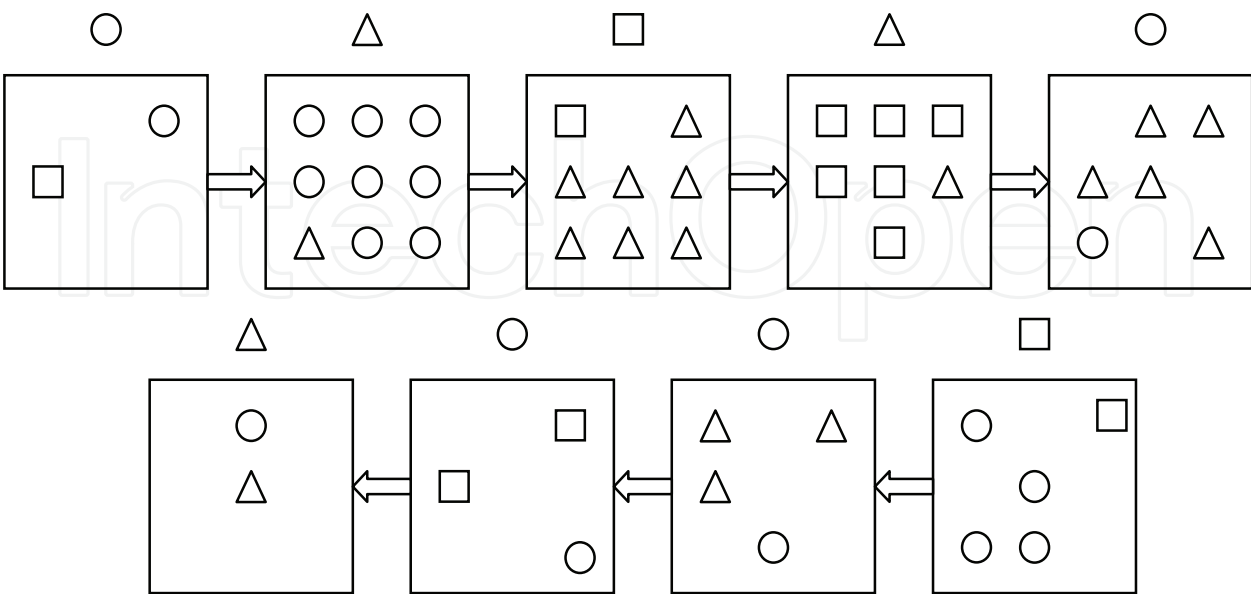

Fig. 7. Steps in the matching-to-sample training procedure. The number of distracters was systematically reduced until the original two-choice test was re-instantiated.

A second example of the promise of the human factors approach for design intervention for those with intellectual disabilities was the work of Wilkinson, Carlin, and Thistle (2008). This study assessed the accuracy and speed of identification of symbols used in aided communication systems. Participants were those with Down syndrome and matched children without an intellectual disability. Visual arrays were manipulated with respect to the color distribution of symbols. In the clustered condition like-colored symbols were grouped spatially. Red symbols clustered in one quadrant of the array, blue symbols in another quadrant, etc. If color cues could be used to restrict attention to limited areas of the visual array, then symbol location, and therefore communicative efficiency, could be enhanced. In the distributed condition, symbols were distributed randomly without regard to color. Categories of objects included foods, clothing, and activities. Thus, the effect of color on visual search was assessed with meaningful symbols rather than the abstract forms used in much of the work discussed above.

Results from this study further attested to the power of visual array manipulations on performances of individuals with intellectual disability. Symbol selection accuracy and detection speed were enhanced significantly in the clustered condition relative to the distributed condition. The magnitudes of the effects for these measures were approximately 10% for the individuals with Down syndrome. Clearly they were able to make use of the color-coding of the arrays to augment their visual search performances. A follow-up analysis indicated that the effect on accuracy is especially pronounced for lower functioning individuals with Down syndrome. These results demonstrate the generality of findings from basic assessments of visual search using abstract forms to problems in intervention design for those with intellectual disabilities.

5. Conclusion

This chapter has presented a novel approach to intervention design for those with intellectual disabilities. Too often the assumption has been that those with intellectual disabilities are unable to learn or perform well on tests of cognitive functioning, particularly when compared to their peers matched for chronological and/or mental age. Much of the early work on the cognitive skills of individuals with intellectual disabilities focused on strategy training and generalization, which too often resulted in failure. Even when strategies could be taught and applied in the short term, those with intellectual disabilities often failed to generalize the strategies to novel situations or materials. Effective cognitive interventions simply were not able to be identified, and it may have been a result of focusing too much on trying to change the internal characteristics of the individual with the disability rather than focusing on the promise afforded by decades of cognitive research. The period from 1980 to the present has seen an explosion in the literatures on memory, false memory, and visual selective attention. This has grown from the establishment of standardized methodologies to study memory functioning (e.g., the DRM paradigm) and visual attention (e.g., feature and conjunctive visual search tasks).

The program of research we have undertaken has been founded in the theoretical and methodological developments that have occurred in these literatures. In some instances we have merely applied basic research methodologies to the study of those with intellectual disabilities so that comparisons to this literature can be made. It was this basic research

comparing the performances of those with intellectual disabilities to comparison groups matched for chronological and mental age that showed the often striking similarities in how structural manipulations of visual arrays similarly influence the cognitive functioning of these groups. Certainly substantial differences exist between those with and without intellectual disabilities, but the basic effects of structural manipulations of visual arrays on cognitive performance are the same. Manipulations that affected the functioning of those without disabilities similarly increased or decreased the performances of those with intellectual disabilities. This level of similarity unlocks the promise of decades of basic cognitive science for those with intellectual disabilities. Possibilities for intervention are made immediately apparent. The findings from hundreds of studies across dozens of years can now be assumed to be directly applicable to those with greatest need for cognitive intervention. The priority now is to apply this work directly to those with these needs.

Some of the guiding cognitive principles of our work on memory have been the benefits of generative processing, the importance of variable cueing (i.e., encoding variability) for recall, and the power of the shift from uncertainty to resolution (i.e., the "aha" effect) during problem solving. These are well known phenomena in cognition that we have applied to the design of our memory enhancement procedures for those with intellectual disabilities. These techniques were selected not only for their powerful influences on memory but also for their ease of application within the "front-end" design approach we believe is most fruitful for enhancing memory in those with intellectual disabilities. Careful and considered design of encoding tasks, based on these principles, can be used effectively to engage memory-enhancing cognitive processes without the need for direct instruction. Fading pictures from blurry to clear over the course of several seconds does not necessarily determine that individuals will generate potential solutions during the fading sequence, but most individuals do engage in this generative activity spontaneously when presented with such displays. Participants in the flicker task do not attempt to remember the objects they reject so that they can serve as retrieval cues on a later memory test. But in doing the flicker task the activity of attending to and rejecting potential solutions does enhance memory. Fading and flicker are quintessential examples of generative encoding tasks that engage the learner with the material to be remembered and induce cognitive processes that enhance memory.

The "aha" phenomenon often is attached to generative encoding contexts. Typical generation tasks involve working from some cue (e.g., a word fragment), considering alternative possibilities, and eventually settling on the best solution. During the period in which alternative solutions are being considered, sophisticated cognitive processes are being undertaken. In addition, the learner is placed in a cognitively uncomfortable situation of uncertainty. The ultimate resolution relieves this uncertainty and often results in a feeling of pleasure or success. That this resolution in and of itself can enhance memory just adds to the power of these manipulations and tasks. Further, these generative, problem solving, tasks are well liked and motivating for the students. Typically participants in these studies are highly engaged with the task and can become quite competitive. They want to be the quickest to find the changing object in the flicker task, to identify the object slowly fading into focus, or to discover the correct word-fragment completion in generation. This level of engagement with and enjoyment of participating in these tasks attests to their promise for applications in education.

The studies we have conducted on false memory in those with intellectual disabilities grew from our general interest in memory and the common finding that those with intellectual

disabilities are particularly prone to false reports. We believed the basic science on false memory reduction was particularly relevant, therefore, to this population. Our work has replicated the high false report rate in those with intellectual disability and demonstrated methods for presenting material for learning that decreases the influence of such reports on overall memory accuracy. Our most recent work in this area has showed that visual and auditory-visual presentations provide distinct advantages for long-term memory, both in terms of memory for learned items and for reducing false reports. We believe this has direct relevance in education with regard to the design of computer-based teaching programs and the design of visual supports for learning.

The work completed in our laboratory on visual search represents the most comprehensive series of studies involving those with intellectual disabilities to date. We have used standard visual search methodologies from cognitive science and created new methods (i.e., the guided search task) or creatively adapted existing methods to the study of visual search (i.e., the flicker task). This basic research provided the knowledge base to design novel applications for enhancing learning and communication in individuals with an intellectual disability. The work of Mackay et al. (2002) demonstrated the marriage of this cognitive science with applied behavior analysis. From a behavioral perspective, establishing the "first instance" of correct responding so that it can be reinforced and increased in probability for later trials is a challenge. The visual search work completed in our laboratory provided the foundation for re-designing the matching to sample task in a manner that would make this "first instance" more likely on even the first presented trial. The work of Wilkinson et al. (2008) demonstrated what we consider one of the most promising applications of this work on visual search. Many individuals with intellectual disabilities also need significant communicative support. Many use computer-based communication aids that require selection of symbols from heterogeneous visual arrays. We have found that the design of these communication devices often is done without regard to the principles of cognitive science or human perception. Greater attention to these principles could greatly facilitate communication in these users. One of the major challenges for users of communication aids, for example, is the slow speed of communication (Wilkinson & Hennig, 2009). Selecting symbols from visual arrays is much slower than verbal communication and therefore can lead to frustration for both the communicator and their audience. More informed design of these communication aids, based on well-established principles of cognitive science, could lessen this hurdle for many. Even the relatively simple use of color grouping by Wilkinson et al. (2008) had a demonstrated positive effect on both the accuracy and speed of symbol selection in a group of individuals with Down syndrome.

The purpose of the present chapter is to demonstrate the strong theoretical foundations of the human factors approach to intervention for those with intellectual disabilities and to show the progress made to date in applying principles of cognitive science to the study of individuals with intellectual disabilities. Because this is a relatively novel and recent approach to intervention, however, much work remains to be done. The first challenge is to broaden the foundation of basic science upon which the approach is built. We have used standardized methodologies and found much generality across populations with and without intellectual disabilities but there remain many unresolved issues. For example, the fading technique worked in one study but not in another. We assume this has to do with the nature of the acquisition-test relationships in these studies but more focused work is needed

to address this issue. We also have found variability in findings when comparing individuals with disabilities to mental age matched comparisons. Though in the main these groups have performed similarly, in certain cases those with intellectual disabilities have performed better or worse than the mental age matched comparison individuals. This may be indicative of the problems with mental age matching, but also could be indicative of interesting subtleties of cognitive processing that are as yet not understood. As in all productive areas of science, it seems more questions arise with each new study completed. We hope more investigators find these issues and problems as compelling as we do and will join us in our quest to understand these processes and how best to serve those with intellectual disabilities.

A second challenge for the future is to begin to investigate differences in cognitive performance and reactivity to these types of visual array manipulations across varying etiological groups with intellectual disabilities. As mentioned at the beginning of this chapter, much research has demonstrated that these etiological groups have varying cognitive strengths and weaknesses that may alter the power of these effects. This pursuit could lead to even more targeted interventions for these etiological groups. As one example, we have been pursuing an investigation comparing the visual search skills of those with intellectual disabilities, particularly Down syndrome, to those with autism and an intellectual disability. There have been several studies reporting that individuals with autism perform exceptionally well on visual selective attention tasks, including visual search (e.g., Joseph et al., 2009). However, these studies have involved participation of individuals with autism with typical levels of intelligence. This is a quite different population than we have typically involved in our research. We expected that individuals with a dual diagnosis of autism and intellectual disability would perform very differently from those with high-functioning autism. However, much to our surprise, to date we have found that those with autism and low levels of measured intelligence (i.e., IQs less than 70) also show this distinct processing advantage in visual search. If this patterns remains to the conclusion of this study it certainly will have significant implications for understanding autism and for intervention design. This population may be particularly responsive to manipulations of visual array structure. Similar comparisons across other etiological groups such as those with Fragile X syndrome, Prader-Willi syndrome, or Williams syndrome would add much to our understanding of intellectual disabilities and the design of focused cognitive interventions for these varying populations. We believe the approach to intervention described in this chapter is particularly well suited to these challenges and will have broader influence as the research foundation expands in the future.

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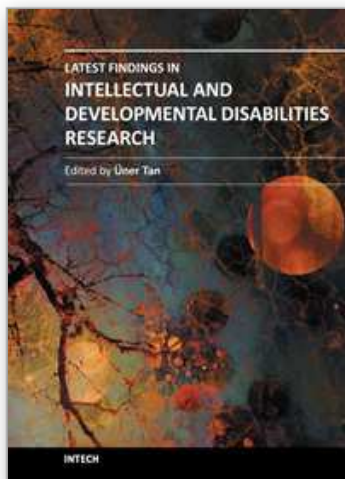
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