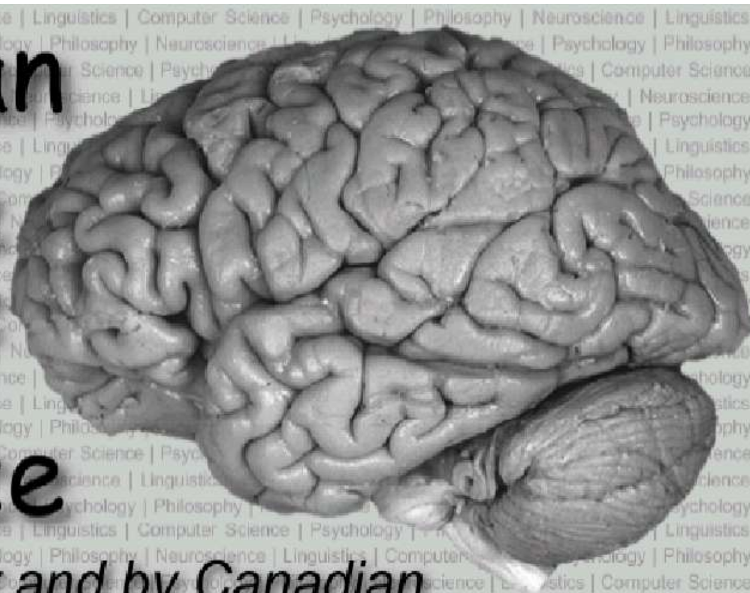
Canadian Undergraduate Journal of Cognitive Science



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IN THIS ISSUE:

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The Canadian Undergraduate Journal of Cognitive Science is an electronic journal published by the Cognitive Science Student Association at Simon Fraser University. Our aim is to provide a forum for students to share work among peers and gain valuable experience in the process of getting an academic paper published. As a publication, CUJCS provides a unique reference for students, showcases research by other undergraduate students, improves the contact and exchange of ideas between Canadian students and cognitive scientists alike, and illustrates the interdisciplinary work that is the hallmark of cognitive science. Although preference is given to Canadian students, contributions from students elsewhere are strongly encouraged.

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We're pleased to announce the release of the third issue of the Canadian Undergraduate Journal of Cognitive Science – a journal for the exchange and promotion of ideas between undergraduate cognitive science students. Our aim is to offer a means of disseminating undergraduate research ideas and to provide an opportunity to gain experience in the academic publication process.

In our first issue, we published four diverse works representing three different universities in three different Canadian provinces. Last year, in 2003, we reached an international audience and published a well-rounded assortment of basic and applied research from several of cognitive science's component disciplines. This year we have expanded our scope further, publishing some ambitious theoretic/analytic work by undergraduates in computational linguistics and biomedical imaging, and some sound experimental work by an undergraduate in psychology.

If you are a student, consider submitting one of your outstanding papers from a senior undergraduate class for next year's edition. If you are a graduate student or faculty member in a discipline related to cognitive science, consider assisting us by refereeing some submissions. You can contact us at cogs-journal@sfu.ca.

This year's edition is due to the dutiful efforts of several people. Jed Allen and Taiya Bartley organized the editorial committee early on and held our feet to the fire to ensure timely progress. And without the tireless effort of Rick Gunnyon, the volume of administrative tasks during production would have been overwhelming. Thanks also to Shamina Senaratne and Fred Popowich of the Cognitive Science department at Simon Fraser University for helping us publicize this little project. It's been three years and we hope, for progeny, that future students have the opportunity to publish a first-rate undergraduate journal such as this one.

Enjoy.

Sincerely,

Doug Yovanovich
senior editor
2004

Lexicography in an Interlingual Ontology: An Introduction to EuroWordNet

Peter Jansen
University of Waterloo
pajansen@uwaterloo.ca

EuroWordNet is a multilingual lexical database constructed in the wake of WordNet. The ontological structure of the language-dependent layers, analogous to individual WordNets, through the semantic space of the interlingual index and abstract framework of the top level ontologies are examined. The semantic nature of the interlingual lexicon is examined as it applies to Gruber's principles for the design of ontologies. Benefits of EuroWordNet's design are highlighted.

WordNet was originally proposed by Miller (1990) in an experiment to test an implementation of a model of lexical organization. Up to this point, ontological databases had been particularly small. WordNet was intended as a test of ontology design on a scale far larger than any existing lexical database, progressively incorporating the English lexicon into a large semantic database.

The lexicon is the name given to a linguistic resource that contains our knowledge of words, including semantic data for each word or concept expressed. Concepts can be more then a single word − they can include compounds, such as 'high school', collocations, such as 'best friend', idiomatic phrases, as in 'keep in touch' or 'being under the weather', and, finally, phrasal verbs, as 'taking back' a book to the library, or 'putting on' your shoes before you go to school. Compounds, collocations, idiomatic phrases, and phrasal verbs extend the idea of storing words in the lexicon to storing conceptual information that may not have a lexical representation using a single word. WordNet currently represents a large portion of the English lexicon, consisting of over 115,000 concepts.

WordNet's organizational units are these concepts. WordNet does not contain units smaller than a word, such as phonemic or morphemic information, or larger units such as frames (Minsky, 1975), scripts (Schank and Abelson, 1977), schemas (Rumelhart, 1980), etc., consisting of multiple concepts. WordNet's structure resembles that of both a dictionary and a thesaurus, having qualities of both. A dictionary contains semantic and syntactic information about single words, and is organized by word spelling. A thesaurus contains semantically related words, and is organized by the general concept that a collection of words represents. WordNet contains *synsets*, which consist of a set of words or short word constructs (as discussed previously) which represent a specific concept. These synsets form the underlying structure of WordNet. In essence, synsets are the reason WordNet is a semantically organized dictionary (Fellbaum,1998).

Initially, WordNet was designed to contain only synsets and pointers between the synsets called *relations*. As development progressed, definitions and example sentences were included with the concepts to help contrast related synsets. While WordNet is a lexical database, its definitions sometimes include encyclopedic knowledge to help define the concepts it represents (Fellbaum,1998).

Synsets describe a collection of lexical concepts that are semantically 'identical'. A synset may consist of only a single element, or it may have many elements all describing the same concept. Each element in a particular synset's list is synonymous with all other elements in that synset. For example, the synset {search, lookup} represents the concept of checking to see if something has a specific property. In this context, 'search' and 'lookup' are both semantically equivalent. For cases where a single word has multiple meanings (a *polysemous* word), multiple separate and potentially unrelated synsets will contain the same word.

Synsets are interconnected by relations. Relations in WordNet express simple relationships between synsets. These relations include subclass and superclass relationships (hyponymy and hypernymy), part-of / has-a relationships (meronymy and holonymy), and the antonymy, or opposite, relationship. The concept network can be traversed using these relations, and from one synset a set of relations open a meaningful path to be explored, allowing simple inferencing to take place.

WordNet consists of four distinct semantic networks, one each for nouns, verbs, adjectives, and adverbs (Fellbaum,1998). This design simplifies the network design, as each word class has different semantic relations. For instance, verbs have a relation called troponymy (Fellbaum,1998), which expresses a particular manner of doing something. Both nouns and verbs can be organized hierarchally. *Unique beginners* are noun synsets at the top of a lexicon's hierarchy (Miller, 1998). These include abstract concepts such as abstraction, possession, processes, and states. These unique beginners can serve as a conceptual base for building the semantic network from the most abstract concept towards less abstract, specific concepts and instantiations.

EuroWordNet

WordNet was designed to be used to represent English words and lexical concepts. The EuroWordNet project (Vossen, Díez-Orzas, Peters, 1997; EuroWordNet, 2001), completed in 1999, set out to create a multilingual lexical database relating conceptual information amoung a number of European languages, and to establish a common framework that would allow new languages to be incorporated. At its completion, EuroWordNet combined the Czech, Dutch, Estonian, Italian, French, German, and Spanish languages, and, since the project's end, a number of additional languages have been developed to its specification, including Swedish and Russian (EuroWordNet, 2001).

The EuroWordNet team examined a number of designs for their multilingual system (Vossen et al., 1997). One of the more expansive approaches considered was to map concepts in one language to concepts in each of the other languages. In this way, if the multilingual database consisted of three languages, six different interlingual conceptual mappings would need to exist (one from each language to each other language). For instance, a potential set of mappings might be English to French, French to English, English to German, German to English, French to German, and German to French. The effort required to add new languages in this system becomes extremely large as the number of languages increases. The potential advantage of this method however would be the tailored translations between languages, which may make interlingual mappings more precise.

The actual design used by the EuroWordNet team requires less computational resources, but with some added advantages and disadvantages. The design is as follows. The database is organized into three main layers: the language-dependent layer, the language-independent layer, and the top-layer and domain ontologies. The language-dependent layer consists of a WordNet structured similarly to the English WordNet, containing the concepts for one specific language. Each language-dependent layer is in essence a WordNet of its own for a specific language. These multiple WordNets are then connected to a language-independent lexical database. This database, called the *interlingual index* (ILI), is a WordNet of its own, but unlike a language-dependent WordNet, its synsets link to the synsets of other language-dependent WordNets. The synsets contained in the ILI represent language-independent concepts, free of the lexical constraints of any one language. In this way, the concepts represented in different languages are cross-lingually linked together, and a concept specified in any one language can be translated into any other language connected to the ILI.

The synsets were developed hierarchically between languages by first identifying common 'base concepts', or concepts that were common to all languages, and beginning the database development from these base concepts. Thirty representative synsets were selected by all language-specific developers, of which 24 are noun synsets, and six are verb synsets. In situations where the language-specific developers identified more base concepts, the concepts were further abstracted to the common set of base concepts. In instances where a base concept isn't lexically represented in a language, a close representation is used.

The base concepts are organized into a top-level ontology where the base concepts are hierarchically extended to include closely related hyponyms. The base concepts are divided into two categories in the top-level ontology: high order entities, and first order entities. High order entities are abstract concepts and include events, processes, relations, properties, and states. First order entities are material objects and perceivable quantities. The top layer of EuroWordNet also contains the domain hierarchy ontology, which allows synsets in the interlingual index to be mapped directly to categorical descriptions, for instance, animal, vertebrate, invertebrate, plant, or clothing. The top-level ontology labels and the domain labels have equivalence relations to synsets in the ILI. This design feature is useful in instances where language-independent but domain-specific ontologies designed for a specific task may be required. Linking to a domain ontology may also help select more generic (further away) or more specific (closer) concepts in interlingual translation (Vossen et al., 1997, p. 2).

The ILI contains six different relations specific to the layer's development (Vossen et al., 1997, p. 3-7). These relations are useful in situations where languages don't map well to each other. Some languages have concepts which are not lexicalized in others. For instance, the English word 'head' can refer to any head, but in Dutch there are different words to express either 'human head' or 'animal head' (Vossen et al., 1997, p. 4). This situation represents one of these ILI relationships, HAS_EQ_HYPERONYM, when a concept exists in one language which is more specific than an existing synset in the ILI. Other relations include HAS_EQ_HYPONYM, where a concept is too general for an existing synset and is mapped to a more specific synset, and HAS_EQ_SYNONYM, where concepts in the ILI are synonymous or identical to each other.

A number of desiderata were introduced by Gruber (1993) to help guide the development of and serve in evaluating ontologies (Gomez-Perez, 2003). These guiding principles, which we shall examine as they apply to EuroWordNet, include coherence, clarity, extendibility, minimal encoding bias, and minimal ontological commitments.

The principal of coherence states that

inferences created through the use of the ontology should not lead to contradictions. A contradiction means that the ontology contains incoherent information. The possible sources of contradiction in EuroWordNet could include situations where closely related concepts are independently categorized, or categorized by different developers and, as a result, synsets in the ILI may actually have both hypernym and hyponym relations to another specific synset. This type of error has been minimized at the higher levels of the ontology by using a common set of base concepts to develop each language-dependent WordNet. Automated searches for synsets that contain subclass-of and superclass-of relations to another synset could be used to find such issues, then either the user or automated inferencing (perhaps selecting the most common hierarchical derivation found between the languages) could correct the incoherence.

Clarity is the principle that terms should be effectively communicated. In terms of the structure of individual WordNets, definitions to help differentiate semantically similar synsets should be clear. The top-level ontology should also clearly express each base concept. Due to the highly abstract nature of these concepts, the base concepts may be best illustrated through elaborating subordinate nodes, perhaps through multiple levels. Clarity would not seem to apply to the interlingual index, as the concepts it contains are purely conceptual and must be interpreted into a language in order to be linguistically perceived.

Extendibility is the guiding principle behind the design of EuroWordNet. The specifications allow additional languages to be mapped into EuroWordNet's structure with a minimum of effort. The principal of extendibility states that an ontology should be able to support the addition of hyponyms to existing concepts without modifying pre-existing concepts. The use of a common base-concept ontology developed through examining commonalities between multiple languages suggests that violations of the extendibility principle should be kept to a minimum, and would likely occur in an active revision of the top-level ontologies while adding additional languages. The dynamic, network-like nature of synsets should allow complete extendibility beyond the top-level ontology.

The minimal encoding bias states that concepts should be defined at a ‘knowledge level’ and should not be dependent on a symbolic level of encoding. This principle alludes to the use of the common top-level ontology using common base concepts in the development of the language-dependent WordNets. In this way, concepts in all languages are build upon this highly abstract layer, which should minimize the bias that could exist if the language-dependent ontologies were built upon unique top-level ontologies.

Finally, the notion of minimal ontological commitment signifies minimizing specificity of information that could exist in different formats. This is an especially important consideration in a cross-cultural, interlingual database. Examples of this bias could include measurements such as dates, spans of time, distances, and intensities. The synset nature of EuroWordNet elegantly expresses the spirit behind this principle by expressing information semantically. Problems where encoding biases may occur could include the synset definitions in each language, which may state each language’s specific method of interpreting some concept such as measure or quantity.

EuroWordNet attempts to incorporate a large portion of the semantic lexicons of multiple European languages in a common framework. The design of this framework is flexible enough to allow the relatively easy addition of new languages, and scales tractably both in terms of computational resources required to process the lexical database, and the work required to create new linguistic databases and connect them with EuroWordNet. The semantic nature of synsets embodies many of Gruber's (1993) principles of ontological development, and combined with systems for semantic disambiguation, could form an impressive interlingual translation system. While the project was officially completed in 1999, the specification continues to be used and nearly three times the number of languages originally supported have individual WordNets developed and can be linked to EuroWordNet's interlingual index. ■

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Effects of Techniques of Receptive Meditation and Relaxation on Attentional Processing

Jesse R. Rutschman
Earlham College[1]
rutscje@earlham.edu

Previous research has indicated that receptive techniques of meditation improve one's ability to sustain, distribute, and divide attention. However, relaxation has also been found to improve attention. Here the effects of receptive techniques of meditation and relaxation are compared on two groups of participants performing a divided-attention task. It was hypothesized that meditation would lead to a broader, more flexible, and more sustained attentional style. Meditation was not found to enhance overall attentional capacity more than relaxation, however it did lead to increased attentional flexibility and sustainment.

Although a powerful tool for reducing anxiety and inducing relaxation, meditation's most important function is to train one's attention (Goleman, 1988; Naranjo & Ornstein, 1971). Some investigators have had success in using meditative techniques as therapeutic methods of attention control training for individuals with mental health problems or attention deficit disorder (Eugene, 1999; Ferguson, 1976; Morris, 1976). Nonetheless, the majority of research on meditation has not been concerned with its attentional effects, and the vast majority of research has focused on transcendental meditation (TM) without distinguishing it from other forms of meditation. Clearly, the investigation and application of various techniques of self-regulation that can alter or enhance attention, has powerful implications for education and mental health.

Although there are a multitude of meditative practices, researchers have generally been able to classify them into two categories: concentrative meditation or mindfulness meditation. As noted by Shapiro (1984), the practice of these different techniques utilizes different attention styles. In concentrative meditation practices, such as Raj Yoga, the practitioner utilizes what Shapiro refers to as 'zoom-lens attention,' focusing on a specific object (an event, image, or sound), thus trying to refine all of his or her attention to a single focal point. In mindfulness meditation practices such as Zen meditation or Vipassana, the practitioner utilizes 'wide-angle-lens attention.' Here one extends their attention to the entire perceptive field. Mindfulness practitioners try to attain a state of receptivity, becoming aware of any and all emergent thoughts and sensations without becoming actively involved in them.

[1] I would like to extend a special thanks to professors Kathy Milar, who provided me with help and guidance in conducting this research, and Michael Jackson for his helpful comments.

Transcendental meditation integrates features of concentrative meditation (i.e. it utilizes a vocal 'mantra'), however in terms of its essential cognitive qualities it can be described as receptive (Roth, 2002). Shapiro's different strategies of attention have been attributed to different processing centers in the brain (Pribram & McGuinness, 1975), as well as different physiological patterns reflecting habituation (Dunn, Hartigan, & Mikulas, 1999; Kasamatsu & Hirai, 1969).

An enhanced attentional capacity has been found as a result of mindfulness meditation, concentrative meditation, TM, and relaxation, however the implications of all of these findings vary (Travis, Tecce & Guttman, 2000; Valentine & Sweet, 1999; Yesavage & Rolf, 1984). Valentine and Sweet (1999) found that both concentrative and mindfulness practitioners had improved sustained attention on a continuous performance task (Wilkin's counting test) in contrast to control participants, however mindfulness practitioners displayed less distraction to unexpected stimuli. According to Shapiro's (1984) model of attentional strategies, whereas practice of a 'zoom-lens' strategy of attention should intensify one's orientation to a single object or continual task, practice of a 'wide-angle-lens' strategy of attention should lead to an enhanced readiness to differentiate between, and attend to varying objects or tasks.

Psychological differentiation can be examined through the lens of field dependence. Witkin (1977), in Bloom-Feshbach (1980), refers to field dependence as an undifferentiated, global style of perceiving things, whereas field independence is the ability to experience items as a distinct from their background. An enhancement in the ability to differentiate between different sets of stimuli and to appropriate attention among different tasks demanding different attentional styles can be seen as one corollary of field independence. Testing regular practitioners of TM and non-meditating controls on several measures used to test field independence (the Autokinetic Test, the Rod-and-Frame Test, and the Embedded-Figures Test), Pelletier (1974) found that, TM practitioners had a more increased perceptual acuity and better field independence. Pelletier's findings have been supported by other researchers (Rani & Rao, 2000).

Performance on divided-attention tasks has been found to improve both as a result of TM and relaxation (Travis, Tecce, & Guttman, 2000; Yesavage & Rolf, 1984). Travis, Tecce, and Guttman (2000) related performance on an auditory-response/letter-recall task of TM practitioners to self-reported levels of transcendence experienced during meditation. They found that participants who had reported more transcendent experiences showed quicker reaction times, reduced effects of distraction, and according to EEG and EOG measurements, a heightened physiological preparedness for response. Yesavage and Rolf (1984) implemented a similar divided-attention task, on a group of elderly people and found that a reduction in anxiety through relaxation techniques enhanced their reaction times on both tasks.

Thus, enhanced attentional capacity has generally been found to be a result of meditation as well as relaxation. However, since certain forms of meditation have also been recognized as effective relaxation techniques (Eppley, Abrams, & Shear, 1989; Zipkin, 1985), the question of whether enhanced attentional capacity can be attributable to special features of meditation or simply to relaxation has not been empirically answered. Physiological differences found between concentrative meditation, mindfulness meditation, and relaxation may indicate possible corresponding attentional differences (Dunn, Hartigan, & Mikulas, 1999). A comparative study on the attentional effects of meditation and relaxation is needed.

The purpose of the author's study was to investigate the effects of receptive forms of meditation, such as mindfulness and TM, and simple relaxation on the process of attentional distribution in divided-attention tasks. As in the studies conducted by Yesavage and Rolf (1984) and Travis, Tecce, and Guttman (2000), the divided-attention task used for this study employed a continual visual task (in this case a visual rotary pursuit) as a primary task, and an auditory stop task as a secondary task. It was presumed that performance on a primary task would reflect centralized attention by requiring the majority of one's attention continuously, whereas performance on a secondary task would reflect residual attention by demanding additional attention sporadically. In the current study, it was presumed that the visual rotary pursuit would engage centralized attention, since it involved continuous focus and coordination and would elicit a habituation response, whereas the stop task would engage residual attention, since it only demanded sporadic attention, and does not rely on a habituated response. Participants performing these tasks were a sample of self-reported mindfulness meditation practitioners and relaxing controls.

Overall, in contrast to the relaxation control group, the author hypothesized that after treatment, meditators would display greater attentional capacity, greater attentional flexibility, and a more sustained attention. The hypotheses can be clearly stated as follows:

1. Practitioners of meditation would exhibit a greater overall attentional capacity after meditation than would relaxed controls on both primary and secondary tasks, which would be reflected by a higher composite score for performances on both tasks.
2. Practitioners of meditation would exhibit greater attentional flexibility after meditation than would relaxed controls, which would be reflected by a comparatively greater improvement in secondary task scores than in primary task scores. Attentional flexibility was gauged in this study by one's reflected ability to respond with readiness to stimuli that have not been habituated, such as a randomly activated buzzer.
3. Practitioners of meditation would display a more sustained attention across trials after treatment than would relaxing controls. This would be characterized by a greater degree of consistency in scores between trials after meditation, suggesting a less rapid decline in attentional capacity, and less modal shifting in attention distribution.
4. Overall, both relaxing controls and meditators would display attentional enhancements after treatment, however findings would be more limited for relaxation.

Method

Questionnaire

After consenting to the experiment, all participants in the study completed a brief questionnaire before they were tested. The questionnaire asked participants if they regularly practiced a technique of meditation, had them ordinally rate both the frequency of their practice and their level of experience, as well as assessing possible factors that may interfere with the participants' ability to relax or attend to tasks (i.e. ADHD, hypertension). A dual forced choice item was on the questionnaire instructing meditating participants to determine whether or not they practiced a form of mindfulness meditation or concentrative meditation according to a self-assessment by choosing between the following descriptions: Concentrative– the meditator focuses his or her attention on an internal or external object (e.g., sound, word, bodily sensations, etc.) while minimizing distractions and bringing the wandering mind back to attention on the chosen object; Mindfulness– the meditator focuses on the present moment. The meditator focuses his or her attention alertly but non-judgmentally on all processes passing through the mind.

The descriptions used for both forms of meditation were based on descriptions of the techniques given in many published texts on meditation (Davidson & Goleman, 1977; Naranjo & Ornstein, 1972). The questionnaire can be found in Appendix A.

Participants

Participants were 35 undergraduate students, 16 males and 19 females (age range 18-24 years), however only data from 31 participants (males=14, females=17) were kept for analysis. Participants volunteered through personal contact, public advertisements and announcements made in psychology courses (where they received course credit for participation), a Hinduism and Buddhism course, and a meeting for meditation of a campus Buddhist group.

Seventeen participants (7 males, 10 females) did not report regularly practicing a technique of meditation as described on the questionnaire. All of these participants were assigned to the relaxation control group. Fourteen participants (7 males, 7 females) reported that they regularly practiced a form of mindfulness meditation, which included Zen and Vipassana, as well as other unspecified techniques. Two of these participants (1 male, 1 female) reported that they practiced TM, and were included in this study since they had chosen mindfulness meditation as the best description of their technique on the questionnaire. Three of these participants had reported prior to testing that they had regularly practiced both a mindfulness technique as well as a concentrative technique (1 male, 2 females). These participants were assigned to the meditation group and instructed to practice a mindfulness technique during the experimental session. Reported experience levels of meditators ranged from one month of practice to over 9 years, with the majority of participants having practiced for more than 3 years. The frequency at which participants reported meditating, ranged from three times daily to only twice a month.

Three participants reported that they exclusively practiced a form of concentrative meditation (1 male, 2 females). Data collected from these individuals was excluded from the main data analysis. Additionally, data from one male participant was excluded for failure to fully follow instructions. All participants included in this study reported being right-handed.

Apparatus

A Lafayette Instruments model 30013 photoelectric rotary pursuit with stylus, a model 63035 visual choice reaction time apparatus, and two model 54030 stop-clocks, were used for the divided-attention task. A handheld Texas Instruments stopwatch was also used to time activation of the reaction time apparatus. The rotary pursuit was set to rotate clockwise at a speed of 40 RPM. Only the auditory stimulus buzzer on the reaction time apparatus was used for the experiment.

Procedure

Participants were instructed to operate the rotary pursuit table, and simultaneously respond to the reaction time apparatus immediately whenever activated. The rotary pursuit table used in this study comprised of a light stimulus, which rotated clockwise around a rotary wheel and was displayed on a plate-glass screen. Using a magnetic stylus, participants were directed to track the light's rotations as precisely as possible around the screen, and their performance was recorded automatically as the cumulative number of seconds the stylus accurately traced the light. The cumulative score was referred to as 'time-on-target.' The reaction time apparatus used in this study was set so that the researcher could spontaneously activate an auditory buzzer by pressing a panel. In order to deactivate the buzzer participants were required to press an opposing panel and cumulative reaction time was automatically recorded in milliseconds.

Once ready to begin a trial, the researcher signaled to the participant and started a handheld stopwatch as he or she began the task. The researcher activated the buzzer on the reaction time apparatus based on a randomized series of time intervals as displayed on Table 1 on the following page. The buzzer was thus activated at random intervals, though they were no longer than 6 seconds in succession. At the end of a trial, participants were instructed to withdraw the stylus from the rotary pursuit until the beginning of the next trial.

Reaction Time Apparatus Activation Times (s)

Practice	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
2.5	3	4	6	6	4	1.5	0.5	5
4.5	5	8.5	8	9	8.5	4.5	2.5	9.5
6	10.5	12.5	11	11	9.5	8.5	6.5	15
11	13	15.5	12.5	13	10	11.5	12	15.5
15	14	19	16.5	17.5	12	12.5	18	17.5
20.5	17	24.5	17	23.5	17	17	22.5	23.5
22.5	19	26	23	29	22.5	18	23	24.5
27.5	20	30	26.5	31	26.5	22	27.5	27
29.5	25.5	31	31	33.5	29.5	23	30.5	29.5
	30.5	31.5	34	34	31.5	26	31	31.5
	34	34	38.5	35	35.5	31.5	31.5	32.5
	37	35	42.5	41	38	33.5	34	36.5
	42.5	37	45	46.5	40	35	38	39.5
	44	40	48	47	41.5	38.5	44	43
	47.5	44.5	50.5	49.5	44.5	39.5	50	47.5
	51.5	46	52	51	45	40.5	51	50
	54	50.5	55	52.5	48.5	42.5	53	51
	58.5	56	58	55.5	53	48	54.5	52
		59			55.5	52	58	53.5
					58.5	54.5		57
						56		
						59		
	[	Trial Series A		]	[	Trial Series B		]

Table 1: Table of randomized intervals for activation of reaction time apparatus[2].

An initial 30 sec practice trial was performed, and then the apparatus was rearranged so that the participant could then perform a practice trial using opposite hands. Practice trials were then followed by a block of four 1 min trials, and another block of four 1 min trials after rearranging the apparatus to switch hand-task pairings once again. Apparatus was initially arranged prior to each session so that half of that participants (N=15) would perform the first block operating the rotary pursuit with their left hand and the response panel with their right hand, whereas the other half (N=16) would perform the first block in the opposite manner. Trials immediately succeeded one another only allowing time for data collection or the rearranging of apparatus between blocks. Response time to the buzzer on the response panel (ms), as well as rotary pursuit accuracy score (sec.) were continuously being recorded by stop clocks during trials, which was documented by the researcher and the clocks reset after each trial.

During the testing session all participants performed the divided-attention task in the same assigned order both before and after meditation or relaxation to collect both pretest and posttest scores.

Following the collection of pretest scores, participants were instructed to leave the testing room and sit anywhere they wished to in the treatment room. Lights were controlled to a low setting and pillows were provided. Participants in the meditation condition were instructed to make themselves comfortable and to meditate, sitting upright, and using the technique that they had reported on the questionnaire. Participants in the relaxing control group were given both verbal instructions and an instructional script with guidelines for a relaxation technique (see Appendix B). The technique was designed by the researcher and aimed at eliciting relaxation without additionally conditioning one's attentional state. It instructed participants to initially take deep easy breaths, but essentially it did not encourage them to focus or expand their awareness continuously as they would if meditating. Relaxing participants were instructed to sit upright and not to sleep, but in contrast to the meditation condition they were allowed to shift their bodies for comfort and keep their eyes open or closed as they pleased. All participants were told that they had an initial 3 minutes to get comfortable before they would begin meditation or follow the instructions given for the relaxation technique, and the researcher left the room. Participants were timed for 23 minutes, and at the

2 The intervals displayed on this table were compiled from a random number generator (http://www.random . org). The researcher attempted to counterbalance the order in which the blocks (trial series) were implemented, so that some participants (N=12) would respond to block B and then A, and some (N=19) would respond to block A and then B, although balancing was not entirely successful in general or within treatment conditions.

completion of this time were gradually awakened from their state by the researcher slowly raising the lights.

After treatment all participants were given 1 minute in which they were told they could stretch out and readjust to a more waking state. After this minute had passed participants returned to the testing room for the collection of posttest scores.

Results

The dependent variables were participants' time-on-target (s) for the rotary pursuit task, and their mean reaction time (ms) for the auditory stop task on each trial. A third variable assessed in this study was participants' composite score for divided-attention, which was produced by an index of both rotary pursuit scores and mean reaction times. Composite scores were calculated for each trial, and can be expressed as: time-on-target (s)/mean reaction time (s); in which case reaction time was converted from milliseconds to seconds. These scores were divided to provide an index depicting how participants' performance on the two tasks contrasted. This was calculated in attempt to assess participants' overall attentional capacity for performance on these divided tasks.

To test the researchers' hypotheses, repeated measures analysis of variance tests (ANOVA) were conducted on the dependent variables, comparing data from meditators and non-meditators, both before and after treatment. To test the hypothesis that meditation would lead to a higher overall attentional capacity than would relaxation, composite scores were compared for meditators and non-meditators before and after treatment. To test the hypothesis that meditators would exhibit a more increased attentional flexibility after treatment than non-meditators, stop task mean reaction times were compared for meditators and non-meditators before and after treatment. To test the hypothesis that meditators would display a more sustained attention across trials, the researcher tested for interactions between trial scores and treatment conditions for rotary pursuit scores and reaction time.

For composite scores there was a main effect for treatment as indicated by comparing means of pretest and posttest blocks, $F(1,27) = 63.48$, $p < .0001$. The direction of this effect showed an overall improvement after both meditation and relaxation, however no interactions were shown to suggest that the effects of meditation and relaxation significantly differed. Figure 1 consists of figures showing line graphs comparing mean composite scores for individual trials for meditators' and non-meditators' both before and after treatment.

An overall main effect was also shown for treatment when comparing means of pretest and posttest blocks for mean reaction time, $F(1,29) = 13.43$, $p < .001$. A between-subjects analysis for reaction time showed an interaction for treatment condition and treatment effect, indicating a difference in the effectiveness of meditation and relaxation in enhancing stop-task performance across pretest and posttest conditions, $F(1,29) = 4.37$, $p < .05$. Separate repeated measures ANOVA tests for pretest and posttest blocks showed no significant differences between groups prior to treatment, although there was a main effect for treatment condition after treatment, $F(1,29) = 5.89$, $p < .02$. This data indicated that the overall difference between meditators and non-meditators was due to a greater improvement resulting from meditation reflected in posttest scores. Line graphs plotting mean reaction times for both meditators and non-meditators for individual trials both before and after treatment are shown in Figure 2.

For mean reaction times, a marginally significant interaction was also found between treatment condition and trial, $F(7,29) = 2.00$, $p < .056$. Looking at the data presented in Figure 2, it appears that non-meditators generally exhibited a gradual increase in reaction time across trials, whereas meditators' reaction times did not significantly vary across trials, for both pretest and posttest blocks. Separate analyses of pretest and posttest reaction times, did not reveal any interactions between treatment condition and trial attributable to either pretest or posttest performance alone.

Several important findings revealed in this study that were not originally hypothesized, were main effects for sex. Results pertaining to differences in performance across sexes were produced by several repeated measures ANOVA tests. The effect of sex for composite scores was $F(1,29) = 5.503$, $p < .026$. For reaction times alone there was no main effect. For rotary pursuit scores the value was $F(1,29) = 4.198$, $p < .05$. Separate analyses of sex as a factor for meditators and non-meditators showed no effect of sex for meditators, however for non-meditators there were main effects reflected for all indexes: $F(1,15) = 7.019$, $p < .018$ for rotary pursuit scores, $F(1,15) = 8.228$, $p < .012$ for mean reaction times, and $F(1,15) = 9.82$, $p < .007$ for composite scores. Overall, male non-meditators performed better for all variables than did female non-meditators. The overall mean scores for pretest and posttest trials for males and females within the meditation and relaxation treatment groups are shown in Figures 4, 5, and 6 for composite ratio scores, rotary pursuit scores, and mean reaction times, respectively.

Discussion

The results of the current study supported many of the hypotheses, while failing to support others. It appears that overall both meditation and relaxation lead to enhancements in attention, however it appears that meditation specifically leads to improvements that relaxation does not. Both techniques do not appear to differ significantly in their potential for enhancing overall attentional capacity, however the findings of this study do suggest that practitioners of receptive techniques of meditation are able to cultivate a more sustained and flexible attentional style than are individuals who merely relax.

Quicker reaction times in stop task performance were reflected by both meditators and non-meditators after treatment, suggesting that both techniques could have potentially improved attentional flexibility. However, meditators' reaction times improved significantly more than non-meditators' after treatment whereas overall attentional capacity did not. This may be attributable to attentional flexibility since it suggests that meditators displayed more readiness than non-meditators to shift their attention to the reaction time apparatus while centrally engaged with the rotary pursuit. Thus, the current study suggests that meditation leads to a qualitatively more flexible mode of attention than relaxation alone does.

Based on trends suggesting that meditators overall had less decline in their performance on the stop-task across trials, it is also evident that meditation leads to a more sustained mode of attention than does relaxation. Though based on the limited number of trials in this study, it is not certain how much more evident this disparity would differ gradually across more trials. An experiment with a greater number of trials would have had more significant findings pertaining to the effects of meditation on sustained attention.

The significant attentional effects credited to meditation in this study, can only be validly postulated as immediate effects and have yet to be proven. The lack of significant findings regarding any between subjects differences in pretest data for any of the measured variables, suggests that meditation had reflected no notable long-term effects, although there do appear to be some preliminary differences (See the pretest data in Figures 1, 2, and 3). Since the sample used in this study was small and not all meditators had long-term experience, nor meditated with extreme frequency, long-term effects of meditation were not identified. The intention of this study was to investigate the short-term effects of receptive forms of meditation, although a longitudinal study investigating long-term effects would have much greater implications regarding the practical merits of meditation.

The techniques of meditation investigated in this study were chosen mainly because participants practicing them were available. Even though practitioners of transcendental meditation identified their technique as a mindfulness technique, it is not unforeseeable that there may be some significant qualitative differences between TM and other mindfulness techniques, or even between other mindfulness techniques. Such differences were not accounted for in this study.

Another factor that was not accounted for in this study, was possible differences in performance between participants arising from the order in which the researcher activated the reaction time apparatus in implementing trial series blocks A and B in Table 1. Since all intervals were generated randomly, it is not highly likely that there would be significant qualitative differences between series A and B effecting differences in results between meditators and non-meditators, although their implementation was not carefully counterbalanced and such a possibility must not be ruled out. Also, sex differences were found in performance, which may have interfered with differences between meditating and control participants since there were a few more females in the control group. It is foreseeable that in addition to preliminary sex differences in performance ability, there may be some differences in how meditation and relaxation effect attentional processing in males and females, though such interaction effects were not found with such a small sample.

An important theoretical question which must be raised regarding differences in performance of meditators and non-meditators is if meditators are generally more predisposed to become meditators based on inherent cognitive features, which may have had more to do with the differences in attentional effects noted in this study than the treatment itself did. Following models of previous research (Pelletier, 1974; Rani & Rao, 2000), implementing a meditation instructional program on a controlled sample of participants unfamiliar with the technique prior to a similar study would resolve such uncertainties. At any rate, it is highly evident form the current study that there are some immediate effects on attention that can be attributed to meditation and not relaxation, shedding light on some of the potential of using receptive techniques of meditation as self-regulation strategies.

It is evident from the findings of this study that further research with a larger, more controlled sample may increase the significance of findings made in this study, reveal attentional effects that were too small to be significant in this study, as well as providing findings relating to the long-term effects of meditation. A better understanding of how the practice of meditation can help facilitate attention particularly may have some important implications for education and the treatment of cognitive impairments. In particular, this study gives strong support for implementing both receptive techniques of meditation and relaxation as potential tools for enhancing one's attentional capacity, and further support for meditation as a potential tool for improving selective attention and increasing one's attention span. The effectiveness of meditation as an alternative or supplementary treatment for attention deficit disorders has already been addressed, and it has been implemented in many clinical and education settings (Eugene, 1999; Zipkin, 1985).

Findings of this study are consistent with previous research, however unlike previous research this study provides a framework for future research comparing meditation and relaxation in divided-attention processes. In order to investigate the attentional benefits of meditation not relevant to relaxation techniques, it is important for researchers to conduct comparative studies. For further research, the effects of both arousing activity and concentrative techniques of meditation on attention would be worth comparing with receptive techniques of meditation and relaxation. Additionally, further research examining these and other variables relating to the larger framework would test the validity of the claims. ■

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Appendix A

Questionnaire

1) Do you have any cognitive conditions or learning disabilities, which may effect your processing of attention or ability to concentrate (i.e. Adult ADD, ADHD)?
2) Do you have any conditions, which may effect your ability to relax?
3) Do you practice Transcendental Meditation, or some other technique of meditation?

If yes:

4) How often do you practice meditation (circle one. specify technique)?
    a. Rarely (once or twice a month, semiweekly)
    b. At least every week
    c. Several times a week
    d. Daily
    e. Other (explain):
5) How long have you been practicing meditation?
6) Which best describes your method of meditative practice (choose one):
    a. Concentration
        - The meditator focuses his or her attention on an internal or external object (e.g., sound,word, bodily sensations, etc.) while minimizing distractions and bringing the wandering mind back to attention on the chosen object.
    b. Mindfulness
        - The meditator focuses on the present moment. The meditator focuses his or her attention alertly but non judgmentally on all processes passing through the mind.

Appendix B

Relaxation Instructions

I want you to find a comfortable place in the room where you can just sit and relax for a while. There are pillows in the corner of the room, feel free to use them. You will have about 4 minutes to position yourself anywhere, and after these four minutes let me know if you are not comfortable.

For the next 20 min. I want you to just relax. Take a moment to find a comfortable place in the room to sit upright. I want you to start your relaxation by paying close attention to your breathing. Take deep easy breaths in and out, pay attention to the rhythm of your inhalations and exhalations, how it feels in your stomach and how it feels through your nostrils. Then you will relax for twenty minutes and I will tell you when to stop. I want you to use this time as an opportunity to really relax letting in whatever thought may come to your mind. Do not make any extra effort in trying to avoid thoughts, or in concentrating specifically on any one thought. You are free to reposition yourself to make yourself more comfortable at any given time, just as long as you do not stand or move to another part of the room. You may keep your eyes open or closed as you wish, however you may not sleep. If you start to feel sleepy you may want to open your eyes or reposition yourself.

Figures

Fig. 1: Pretest and posttest composite divided-attention scores for meditating and relaxing participants. Vertical lines depict standard errors of the means.

Fig. 2: Pretest and posttest stop task mean reaction times (ms) for meditating and relaxing participants. Vertical lines depict standard errors of the means.

Fig. 3: Pretest and posttest time-on-target rotary pursuit scores (s) for meditating and relaxing participants. Vertical lines depict standard errors of the means.

Fig. 4: Pretest and posttest composite divided-attention scores for males and females within the meditation group and the relaxation group. Vertical lines depict standard errors of the means.

Fig. 5: Pretest and posttest time-on-target rotary pursuit scores (s) for males and females within the meditation group and the relaxation group. Vertical lines depict standard errors of the means.

Fig. 6: Pretest and posttest stop task mean reaction times (s) for males and females within the meditation group and the relaxation group. Vertical lines depict standard errors of the means.

Correlating Changes in QNE Scores to Quantified Changes in Hippocampal Surface Area and Volume in Huntington's Disease Patients

Shahrukh N. Bakar
Medical Image Analysis Laboratory
School of Engineering Science
Simon Fraser University
shahrukh_bakar@hotmail.com

Declines in hippocampal volume have been quantitatively observed in patients with Huntington's disease (HD) by Rosas *et al.* (2003) However, these declines, along with declines in hippocampal surface area, have not been considered with respect to changes in the severity of HD. *Objective:* To quantitatively describe and correlate changes in Quantified Neurologic Exam (QNE) scores to changes in hippocampal surface area and volume in HD patients. *Methods:* Hippocampal structures were manually segmented in temporally-separated MRI datasets of seven HD patients. Hippocampal surface areas and volumes were calculated. Inter-scan changes in these were plotted with changes in QNE scores for each patient. Surface meshes and contours were generated using these data. *Results:* Surface areas and volumes changed significantly between each pair of datasets for each HD patient. Clear correlations with changes in pairs of QNE scores have been observed. *Conclusions:* This study not only confirms statistically significant declines in hippocampal surface area and volume in patients with HD, but also quantitatively correlates them with respect to non-time-based progression of HD, as indicated by the *change* in pairs of QNE scores. The results may be useful in a clinical environment, where observed changes in an HD patient's QNE scores could be used to quantitatively estimate loss of hippocampal surface area and volume; particularly when multiple MRI datasets are not available.

Huntington's disease (HD) is a neurodegenerative genetic disease that causes atrophy in various regions of the brain; such as the caudates and putamen (Aylward *et al.,* 1997; Aylward *et al.*, 2004; Kassubek *et al.,* 2004; de la Monte *et al.,* 1988; Rosas *et al.,* 2001; Slow *et al.,* 2003). Hippocampal atrophy is especially detrimental to memory formation in advanced stages of HD, and can be used in clinicopathological assessments of the progression of the disease.

The severity of HD is tracked by rating a patient on the Quantified Neurologic Exam (QNE) score scale. This standardized scale assigns an overall numerical value from 0 to 129, depending on the degree of incoordination and/or chorea displayed during tasks performed in various sub-tests (Folstein *et al.,* 1983). A lower numerical value indicates fewer motor abnormalities. A large, positive change in inter-scan QNE scores indicates a large deterioration of motor abilities.

Although Rosas *et al.* (2003) have observed large declines in hippocampal volume, changes in hippocampal surface area have not been quantified. Changes in surface area may be especially important to consider, since atrophy modes may not be uniform between hippocampal structures in various HD patients. It is widely believed that general HD symptoms are linked to a loss of hippocampal volume, but the link, if any, with the loss of surface area is unknown. The existence of a correlation between inter-scan changes in QNE scores and changes in hippocampal surface area and volume in patients with HD has not previously been investigated.

Even though the surface area and volume of the hippocampus are likely to change in different ways in patients, it would be especially useful in clinical practice to correlate changes in a patient's Quantified Neurologic Exam (QNE) score to the likely surface area and volume changes that have occurred. Such a correlation would provide additional support in diagnosis and would assist in tracking the progression of HD. Knowing the changes in hippocampal surface area and volume may also be useful in screening patients for recruitment in experimental drug or therapy protocols.

Methods

Segmentation of the Hippocampal Structures

Two MRI datasets ('snapshots') were obtained for each of the seven HD patients from Professor Elizabeth H. Aylward, University of Washington (Seattle, WA). Datasets were acquired on a General Electric 1.5 T scanner. Each dataset contained 124 2D image slices of the head in the axial, coronal and saggital planes. For each dataset, the entire hippocampal structure was manually outlined by the author in 3D Slicer (image visualization and processing software), primarily in the saggital plane. Differences in tissue density between the hippocampus and surrounding tissue, seen as the boundary between light and dark areas in MRI slices, were used with expected anatomical location of the hippocampus as a criterion for defining the shape of the hippocampus. Three-dimensional Visualization ToolKit (VTK) virtual models were created from the outlines and volume and surface area statistics were computed by 3D Slicer from these. Segmentation was repeated eight times to improve the accuracy of data obtained.

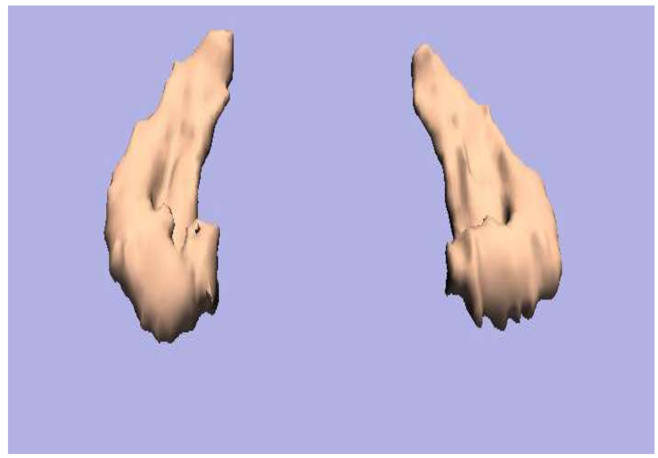

Fig. 1: Screenshot of typical 3D VTK virtual model of the hippocampal structures generated by Slicer.

Calculations

The Mean and 95% Confidence Interval were calculated from the eight hippocampus segmentations; for both surface area and volume in each dataset. This was performed once per dataset; therefore twice per patient. Each patient's inter-scan surface area and volume deltas were calculated by subtracting hippocampal surface area and volume means of the first snapshot from the respective surface area and volume means of the second snapshot. Combined surface area and volume 95% Confidence Intervals were generated from the two snapshots for each patient by adding together respective surface area and volume 95% Confidence Intervals from each scan.

Generation of Surface Meshes and Filled Contour Maps

Changes in the seven patients' hippocampal surface area were stored as a 1 x 7 string in Matlab. Similarly, changes in hippocampal volume, and changes in the patients' QNE scores were also stored as 1 x 7 strings. The change in hippocampal surface area data were plotted as points along the x-axis; the change in hippocampal volume data were plotted as points in the y-axis, and the corresponding change in QNE score data were plotted as points in the z-axis. This produced a three dimensional scatter plot of seven points. Using this scatter plot, Matlab then generated a surface mesh using the 'mesh' feature, with a 'cubic' argument. Filled contour maps were generated using the 'contourf' feature, with steps in the change in QNE scores representing contour areas.

Results

Overall, each of the seven patients showed statistically significant declines in both surface area and volume of the hippocampus between scans, as shown by non-overlapping 95% confidence intervals for each parameter. (Figure 2)

For all seven patients, the loss of surface area and volume appears to be linked: even though the losses may vary in magnitude, they appear to follow a somewhat uniform 'slope'. This indicates similar modes of atrophy amongst all patients. The variation in the magnitudes of the losses may be due to different inter-scan time periods (mean inter-scan time period and S.D. are 3.1 years and 0.9 years, respectively), varying lengths of the unstable CAG repeat in the huntingtin gene on chromosome 4 (The Huntington's Disease Collaborative Research Group, 1993), and varying ages of the patients.

From Figure 2, the volume and surface area delta graph was generated, and is shown below.

By extending Figure 3 into three dimensions, Figure 4 was generated (below). Figure 4 shows the surface mesh and filled contour map generated by Matlab. The filled contour map is shown by itself in Figure 5 (below).

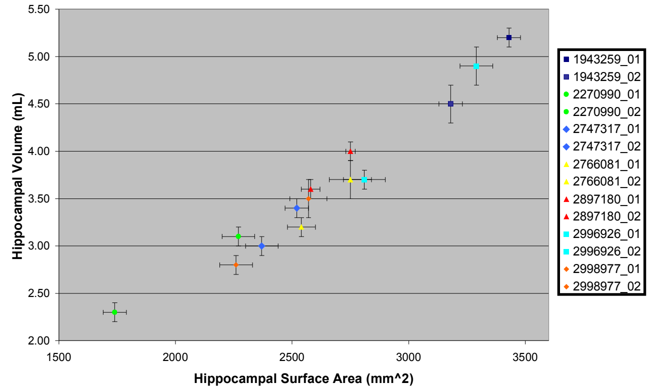

Fig. 2: Overview: Hippocampus Volume vs. Surface Area in Seven HD Patients. xxxxxxx_01 refers to first snapshot, xxxxxxx_02 refers to second snapshot. Bars represent 95% confidence intervals (n = 8 on both axes).

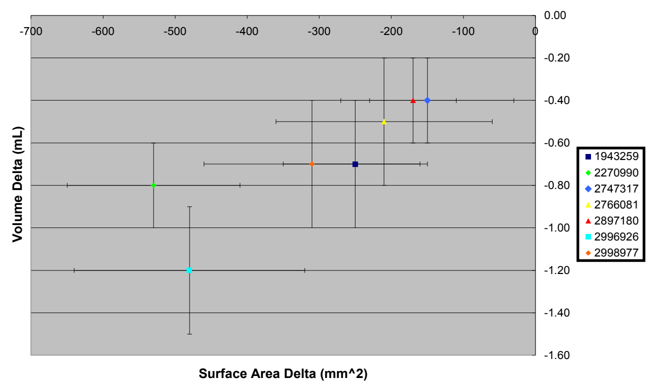

Fig. 3: Hippocampus Volume Delta vs. Surface Area Delta in Seven HD Patients. Bars represent combined 95% confidence intervals.

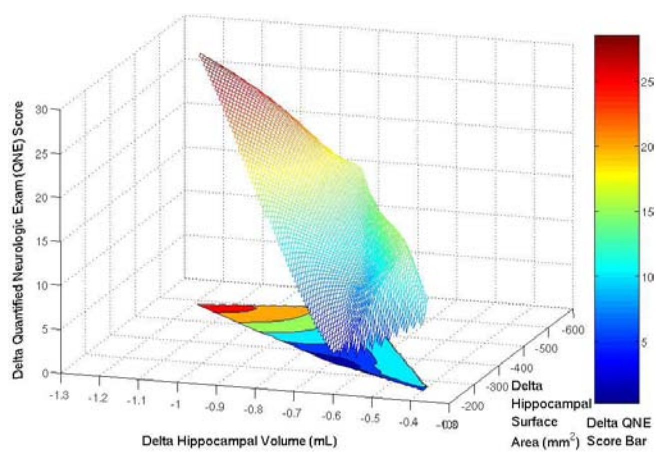

Fig. 4: Overview: Change in QNE Score versus Change in Hippocampal Volume versus Change in Hippocampal Surface Area Surface Mesh and Filled Contour Map for Seven HD Patients. Confidence interval bars have been omitted for clarity. Contour lines are 5 units apart.

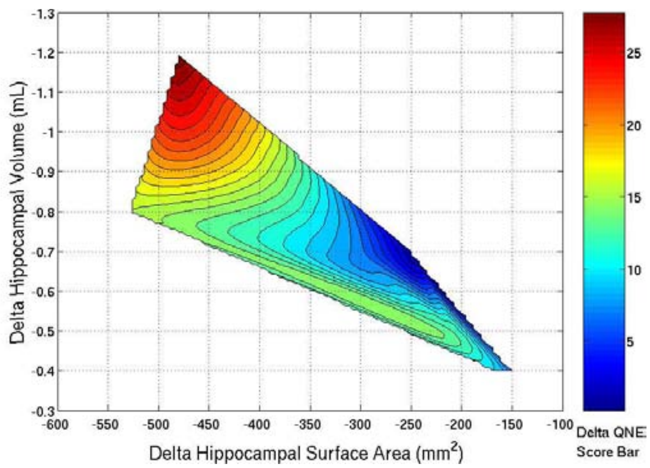

Fig. 6: Change in Hippocampal Volume versus Change in Hippocampal Surface Area Filled Contour Map. Changes in QNE Score values are indicated in steps of 1 unit by contour lines.

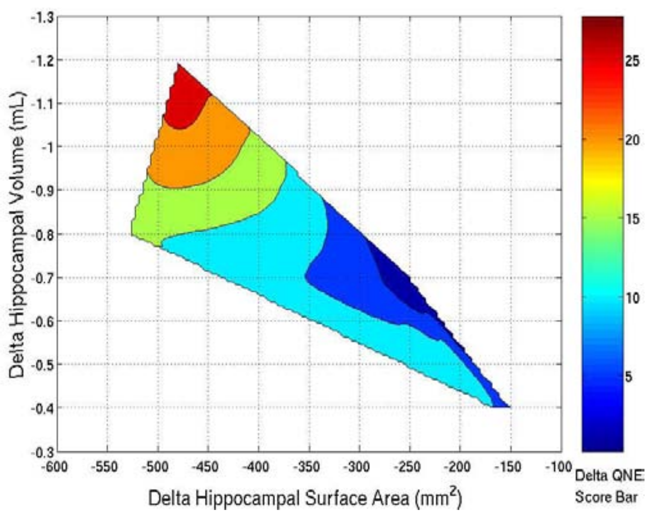

Fig. 5: Change in Hippocampal Volume versus Change in Hippocampal Surface Area Filled Contour Map. Changes in QNE Score values are indicated in steps of 5 units by contour lines.

Discussion

The severity of motor abnormalities (and, therefore, the severity of HD) has already been categorized as 'mild' and 'moderate'; indicated by QNE scores of ≤ 35 and > 45, respectively (Aylward *et al.*, 2004) However, to analyze the contour map generated in Figure 4, it is necessary to establish a *change* in QNE score severity scale. For this study, a *change* in QNE score of 0 thru 10 shall denote 'mild change'; 11 thru 20 shall denote 'moderate change', and 21-30 shall signify 'severe change'. It is important to note that this change in QNE score scale is not time-based, and cannot therefore be used as a standalone indicator of clinical progression of HD. However, a QNE score delta of, say, 10, in 2 years is clearly worse than the same score delta in 20 years.

It is now possible to quantify the estimated loss of hippocampal surface area and volume between two neurological exams of one patient. For example, if the patient has a mild inter-exam *change* in QNE score of 8, then the likely loss of hippocampal surface area and volume would be in the middle of the second-darkest blue zone in Figure 5. For clarity, Figure 5 has been further subdivided into change in QNE score steps of 1 (see Figure 6).

Clearly, a range of values must be given for both loss of hippocampus surface area and volume. For any given change in QNE score, the range of estimated loss for both surface area and volume is shown by the spread of values covered by the corresponding contour area. However, the most likely value is shown by the part of the contour area on which the longest line segment can be drawn, orthogonal to the parameter axis (see next paragraph and pink lines in Figure 6 above as examples).

The contour area for a change in QNE score of 8 is shown by the black arrow in Figure 6. This area shows a change in hippocampal surface area from about -325 mm^2 to -225 mm^2, with the most likely change being about -310 mm^2 (vertical pink line, orthogonal to Delta Hippocampal Surface Area axis). Similarly, the change in hippocampal volume is shown from -0.85 mL to -0.58 mL, with the most likely change being around -0.67 mL (horizontal pink line, orthogonal to Delta Hippocampal Volume axis).

There is a particularly noteworthy feature shown in the contour areas in Figures 5 and 6. For example, a change in QNE score of 0 indicates an estimated change in surface area range from -260 mm^2 to -240 mm^2, with the most likely value of

-250 mm^2, and a change in volume range from -0.75 mL to -0.65 mL, with the most likely value of -0.68 mL. This may be counter-intuitive, since no change in motor abnormalities may seem to indicate no change in hippocampal surface area and volume as well. However, Aylward et al. (2004) reported that striatal atrophy was present in patients with HD years before the disease was observed clinically. Even though the striatal structures do not include the hippocampus, the data in Figures 5 and 6 suggest that hippocampal atrophy exists before HD causes motor abnormalities that show up as a change in QNE score. This feature may be used to provide evidence for or against a clinical diagnosis of HD. For example, assume that a healthy person is diagnosed with HD based solely on the presence of a QNE score of, say, 10. An MRI scan is then performed, and the hippocampus is segmented out and compared with a segmentation from a previous MRI scan (at which time the QNE score was determined to be 0 or very low). If the patient has HD, then the contour area corresponding to a change in QNE score of 10 would show a change in hippocampal surface area and volume range that would encompass the observed changes. However, if large discrepancies are noted between the chart and the observed changes in hippocampal surface area or volume, then further examination, such as genetic testing for the length of the CAG repeat, a second opinion, or verification of the mode of atrophy, is warranted; possibly identifying an incorrect diagnosis or strengthening a correct one.

Knowing the likely changes in hippocampal surface area and volume may also aid in more rigorous screening of HD patients for experimental protocols or drug therapy trials requiring various levels of progression of HD.

This study is limited by various factors. For example, a small sample size of seven HD patients with multiple datasets limits the filled contour map's accuracy and area. This results in very large surface area and volume change ranges being indicated for a given change in QNE score clinically observed. Also, patients with QNE score changes above 25 are not well represented on the contour map, resulting in misleading estimated hippocampal surface area and volume change ranges being generated. Extreme cases, with QNE score changes greater than 30 are not represented at all on the contour map. The small sample size also makes it impossible to tell whether more than one mode of hippocampal atrophy exists in patients with HD. More patients with multiple MRI datasets must be analyzed to improve the accuracy of the contour map, extend its application to severe and very severe cases, and possibly uncover other modes of hippocampal atrophy in patients with HD.

Another source of error is the lack of a completely objective system of defining the hippocampal structure boundaries in MRI slices. At present, a reliable, automated system for selecting and defining the hippocampus is not available. Therefore, segmentation of the hippocampus in MRI datasets had to be manually performed by the author. To help minimize error and variability, manual segmentation was repeated eight times per scan, and was performed by only the author. The development of computer-assisted recognition of the boundaries of the hippocampus in MRI images will undoubtedly increase accuracy and will allow for a greater number of HD patient datasets to be analyzed; while substantially reducing variability and cost at the same time.

In addition, the time period between scans has not been factored into the results or analysis. (In other words, the *rate* of change has not been accounted for; only the change itself has.) However, since the changes in QNE scores, changes in hippocampal surface area, and changes in hippocampal volume are not time-based (i.e. not 'changes per year'), it is unlikely that they would bias the results in any way.

It is also important to note that the pink lines in the filled contour area in Figure 6 do not represent 95% confidence interval ranges for the estimated changes in hippocampal surface area and volume.

Instead, they quantify the *most likely* changes expected for both surface area and volume. The range of possible changes (not necessarily a 95% confidence interval) for both parameters is indicated by the spread of values covered in each parameter by the section of contour area that corresponds to a given change in QNE score value.

Despite the limitations in this observational study, it is now possible to quantify the loss of hippocampal surface area and volume that has occurred in HD patients, from their inter-scan change in QNE score. This will undoubtedly help clinicians chart the progress of the disease and recommend treatment strategies that focus on the now-quantified hippocampal changes that cause HD symptoms; instead of administering treatment based entirely on the gut-level, intuitive and iterative 'wait-and-see' approach.

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