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Editorial

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Teaching Statistics: Am I the Lone Dinosaur?

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KEYWORDS: Teaching statistics; Statistics anxiety.

TEACHING SOCIAL SCIENCE STATISTICS: AM I THE LONE DINOSAUR?

Teaching statistics in a social science department can be a daunting task for the new or part-time faculty member. Students have a wide range of abilities, aptitudes, interests, and motivation levels. Of course, as we all know, many social science students fear statistics. Approximately 80% of the graduate students experience statistics anxiety.[1] Although this anxiety might hinder performance, many survive the course. What I find interesting is that some of these students may go on to teach undergraduate statistics courses as part of their graduate teaching duties. Therefore, teaching statistics certainly can alleviate anxiety as one is forced to know the material well and convey it in a cogent way to undergraduates.

If graduate students fear statistics courses, then it is highly probable that the undergraduates fear statistics as well, if not more so. These anxieties may include fear of asking questions, having difficulty in providing conclusions from the data, and perhaps being intimidated by the faculty member given the topic and knowledge base.[2] The mathematics in this course is fairly simple, yet the concepts may be somewhat abstract. Hence, how does one make an abstract concept easy to digest? Perhaps one way is to provide a real-life example.[3] For example, in my discussion of the Central Limit Theorem, I will explain how the sampling distribution of the mean approaches normality when sample size increases. From a more humorous real-life perspective, I will explain how a supermodel who stands six feet tall and weighs 110 pounds can eat candy bars and milk shakes (which would be akin to sample size) to become more "normal". Not only is this a real-life example that many of us can relate to, but also there is humor. This can be one way to make statistics come alive.

There are almost as many ways to teach statistics as there are statistics professors. For example, in our psychology department, there are three tenured faculty members who teach the majority of the undergraduate sections. One faculty member uses the eyeball estimation method, which is certainly novel. A second professor uses SPSS in her course, which is quite laudable. My approach has been to have students calculate problems by hand. These problems include z-scores, confidence intervals, ANOVA, subsequent tests to ANOVA including range tests, and correlation. However, my philosophy starts on the first day of class in which I explain that statistics is simply telling a story with numbers. Moreover, this story becomes more complete based on advanced testing, if appropriate. These stories transcend disciplines. Although the majority of students are in psychology, there are some in hotel administration, biology, nursing, anthropology, and kinesiology, just to name a few. In order to make statistics relevant for these students, I will provide salient problems that could be of great interest ranging from testing different types of drugs for reduction of Ebola or Zika Virus symptomatology to discussing differences among hotels on the Strip with regard to quality of stay.

There are some statistics that can be difficult for the student to conceive as having any real-life meaning. For example, using the descriptive statistic of z-scores, the student is introduced to examining what percentage of folks score above or below the mean. Although students may have a modicum amount of interest in examining this issue, perhaps showing how one can convert GPA, GRE scores, letters of recommendation ratings (usually from 1-5), and interview ratings (usually from 1-5) into z-scores and then averaging them or providing spe-

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cific weightings for predicting an incoming class of prospective graduate students might foster greater interest. For example, one can provide cutoff scores such that anyone higher than 0 (the mean) to +.5 would be waitlisted, whereas those at +.5 and above would be given acceptance and an assistantship. Those below the mean (z-score of 0) would be given rejection letters. A similar example can be used for job applicants. As a sports aficionado, I also mention that it would be nice if professional athletes used z-scores as part of their contract negotiations. For example, if one is a quarterback, then what is the overall (average) z-score for touchdowns, yards thrown, yards per pass attempt, completion percentage, and interception percentage?

After addressing the real-life situation issues as we go through the course, students usually struggle with standard study habits, that also exacerbates the anxiety. Mnemonics have been used as one possibility for remembering information in statistics.[4] For example, remembering the differing types of measurement, nominal, ordinal, interval, and ratio, one could use No Oil in Rivers[5] or Never Own Impotent Rabbits. Although I rarely use this type of device in my course, I do believe in making information more personal. For example, I usually want my students to remember the t values on infinity degrees of freedom at the .05 and .01 levels (1.96 and 2.58) given that they are equal to z. Obviously, these values come in handy for hypothesis testing using z or confidence intervals around the mean with large sample sizes. I usually tell the students that 1.96 was my undergraduate GPA and 2.58 was my graduate one. Their responses are usually priceless. Likewise, when I discuss orthogonal comparisons, I mention that the word orthogonal means independent. Therefore, if you see me on campus on July 4, I hope that you will wish me a happy orthogonality day. Once again, this technique may not only foster learning, but also alleviates some of the student anxiety.

Sometimes we are so focused on our content, that we may forget the human factor. The human factor may consist of eye contact, smiles, and having enthusiastic inflection, for example. These would be components of immediacy[6] which are behaviors correlating with a psychological closeness.[7] Williams[8] studied this concept in a statistics course and found that immediacy (or lack of) accounted for the majority of anxiety concerning students' fear of statistics teachers. Hence, she concluded that if students like the instructor as a person, then they are likely to feel more comfortable and much of the intimidation and fear may go away. One can take this idea a step further. For example, even when students come by the office for help, I might ask about their future plans or give them a quick introduction as to how to apply to graduate school. This type of humanity might allow students to ask questions in class whereas many are scared to do so for a variety of reasons.

Over the years, I have been asked by students and colleagues alike as to why I do not teach SPSS (or an equivalent) at the undergraduate level and constantly make students perform calculations by hand. My contention is that one needs to get through the anxiety process and provide a rudimentary understanding as to how and why these techniques are important both from theoretical and applied perspectives. Using SPSS may provide an added layer of anxiety coupled with simply pointing and clicking to obtain answers without going through the rigor of the math. This can lead to a total and blind reliance on the program, which may be problematic. For example, Levene and Hullett[9] showed how eta-squared and partial eta-squared were mislabeled by SPSS. Although I realize that this may be an isolated example, nevertheless, it is also interesting to show students how many of these formulas are related on a more logical basis rather than through mathematical derivation.

Finally, it is amazing how many different techniques are used by faculty in statistics classes including small-group cooperative learning,[10] learning projects,[11] and dance.[12] Lesser and Pearl[13] also referenced music, food, cartoons, comic strips, magic, movies, and videos, just to name a few additional techniques. They referenced that techniques such as cartoons may foster learning, reduce anxiety, and increase the human element in the classroom. Although there are excellent books on the topic of teaching statistics[14-16] it seems logical that there are no perfect ways to teach statistics. Teaching statistics should be similar to teaching any course. That is, making sure that students are engaged. Nevertheless, to me, if the student obtains a rudimentary understanding and appreciation of the topic and if I also made it a fairly benign process for them, then that is a reasonable expectation and outcome. However, if they can apply this information to additional courses such as research methods or to their own research, then that outcome would be optimum.

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Research

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The Symbolism as a Cheap Channel Code: The Symbolic Language's Role in Cognition

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ABSTRACT

There are different ways in which human beings cognitively handle sources of information. Tasks, such as number guessing, velocity, weight, and extension estimation, can be accomplished through different cognitive strategies – e.g. by counting, or comparing objects' characteristics, and so on. In most cases, these different ways imply different performances and costs to the subject. We offer an interpretation of these "different ways" in terms of different channel codes through which the environmental information is processed by the Central Nervous System (CNS). By considering the channel code's cost and performance, we will distinguish among three categories of codes; prompt processing, working memory, and symbolic coding scheme. The interpretation seems to provide explanations to important questions, such as: Why do we have the internal representation that we have – in terms of colors, extension, and texture? Why are simple theories considered better than complex ones? Why do different representations of a given system, even if conflicting, result in the same action plans (experiments)?

KEYWORDS: Brain processing limits; Information theory; Number guessing experiment; Symbolic language.

INTRODUCTION

In general, there seem to be different ways in which human beings cognitively handle sources of information. Tasks, such as number guessing, velocity, weight, and extension estimation, can be accomplished through different cognitive strategies – e.g. by counting, or comparing objects' characteristics, and so on. In most cases, these different ways imply different performances and costs to the subject. In this paper, I offer an interpretation of these "different ways" in terms of different channel codes through which the environmental information is processed by the Central Nervous System (CNS). By considering the channel code's cost and performance, I will distinguish among three categories of codes; prompt processing, working memory, and symbolic coding scheme. The code metaphor affords alluring explanations to important questions, such as: Why do we have the internal representation that we have – in terms of colors, extension, and texture? Why are simple theories considered better than complex ones? Why do different representations of a given system, even if conflicting, result in the same action plans (experiments)? In most cases, examples will be given through the number guessing experiments, though the general principles seem to be applicable to cognitive tasks broadly.

From the philosophical point of view, the problem of giving a suitable characterization of the role played by symbolic language in our relation with the environment has mostly taken a representationalist format. Philosophers have broadly tried to justify the successful employment of mathematical language in science through notions as 'reference', 'correspondence', 'truth'; all of which seem to suppose a *representing* relation between symbolic language, on the one hand, and the world (or a model of it) endowed of predefined properties, on the other hand. The problem is that this representationalist account seems to provide no sat-

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isfactory explanation of the connection between the organism's representations and its interactions with environment, which is the main organism's purpose.[1-6] From the psychological point of view, the idea of interpreting the symbolic language as a code is not entirely new. Dehaene in 1992, for example, has proposed a model in which different numerical representations are viewed as different processing codes for numerical magnitudes.[7] However, the Dehaene's *triple-code model* provides no clear indication of which mathematical tools should we employ to make this notion of code more precise. Therefore, the twofold aim of this paper is, first, to provide a characterization of the role played by symbolic language in our relation with the environment that can be connected with motor interaction. And, second, to suggest a mathematical formalist in which the code's intuition can be suitable formulated and explored, conducting to more refined models. As a surplus, answers to old philosophical questions seem to emerge.

THEORETICAL FRAMEWORK

The information processing carried out by the Central Nervous System (CNS) is interpreted as the communication system whose performance is measured in terms of control. Therefore, environmental information is processed by the sensorial organs resulting in action plans whose objectives are to keep the organism alive. Whenever an accident occurs I will assume some bit of information had been wrongly decoded – the average over the suffered accidents gives the degree of control – or the lack of control. According to this interpretation, an information processing system is specified by six entities, grouped into three pairs: The source ($p(s)$, d), consisting of a probability distribution $p(s)$ and a distortion function d; the channel ($p(y|x)$, ρ), consisting of a conditional probability distribution $p(y|x)$ and a cost function ρ; and the code (F,G),, consisting of the encoder F and the decoder G functions (Figure 1). For the purpose of this paper, I will be concerned with discrete and finite alphabets.

Definition 1.1 (Source): *A discrete-time memory less source ($p(s)$, d) is specified by a probability distribution $p(s)$ on an alphabet S and a set of Hamming-like distortion functions. Let's take the power set $P(S)$, so that $P(S)=\{\overline{\overline{S}}_1,\ldots,\overline{\overline{S}}_i,\ldots,\overline{\overline{S}}_{2^{|S|}}\}$. Now let us define a set of Hamming-like distortion functions*

$U=\{d_1(S,\hat{S}),\ldots,d_i(S,\hat{S}),\ldots,d_{2^{|S|}}(S,\hat{S})\}$ so that

$$d_i\left(S,\widehat{S}\right)=\begin{cases}0 \text{ if } s=\widehat{s} \text{ e } s\in\overline{\overline{S_i}} \text{ ou } s\neq\widehat{s} \text{ e } s\notin\overline{\overline{S_i}}\\ 1 \text{ if } s\neq\widehat{s} \text{ e } s\in\overline{\overline{S_i}}\end{cases} \qquad 1.1.$$

is called the Accident Distortion Measure, which results in a probability of error, since $Ed_i(S,\hat{S})=Pr_i(S\neq\hat{S})$. This implicitly specifies an alphabet $\hat{S}$ in which the source is reconstructed. As the alphabets are discrete, we call this, a discrete memoryless source, and the probability distribution becomes a probability mass function (pmf).

Intuitively, the source $p(s)$ should be interpreted as one's environment and the 2^S distortion functions as the relevant information to successful interactions in all different situations.

Definition 1.2 (Learning Function): *To choose among the $2^{|S|}$ distortion functions $d_i(S,\hat{S})$, a set of sequences $A_\epsilon^n=\{s_1,s_2,\ldots,s_n\}\in s^n$ is generated according to the distribution of probability $p(s)$, the so-called typical set of S. Then we define an index function L so that*

$$L: A_\epsilon^n \to U \qquad 1.2.$$

is called Learning Function. The learning process is a question of finding out the Learning Function L. The sequences in A_ϵ^n can be interpreted as the typical situations occurring in our world.

Intuitively, each sequence $s_i\in S^n$ should be interpreted as a typical environmental situation – i.e. the rocks falling down, hot air coming up, birds flying, fishes swimming and not otherwise – and the Learning Function as the skill of paying attention to the right things in every situation.

Definition 1.3 (Channel): *A discrete-time memoryless channel ($p(y|x)$,ρ) is specified by a conditional probability distribution, $p(y|x)$, defined on two discrete alphabets X and Y and a non-negative function*

$$\rho: X \to R+ \qquad 1.3.$$

called the channel input cost function. When the alphabets are discrete, we call this a discrete memoryless channel.

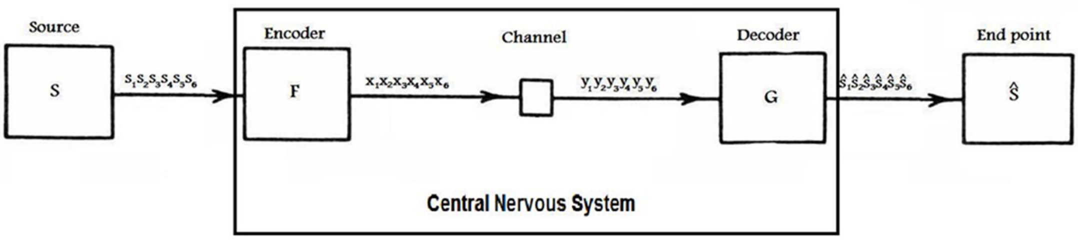

Figure 1: Information system.

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Intuitively, the notion of channel should be interpreted as the relation between perception and action and the cost function as a measure of the processing costs.

Definition 1.4 (Source-Channel Code): *A source-channel code (F, G) of rate R is specified by an encoding function*

$$F{:}S\rightarrow X_n, \qquad 1.4.$$

yielding code words $x^n(1), x^n(2), \ldots, x^n(2^{nR})$, the set of code words is called the *codebook* or *coding scheme*.

And a decoding function

$$G{:}Y_n\rightarrow \hat{S}, \qquad 1.5.$$

such that k/n = R, where n is for n uses of channel and k is for number of bits per source symbol.

Intuitively, S is the source information that affects the organism through stimuli generating an internal representation X_n. The internal representation is processed generating an action plan Y_n, which is decoded as real actions $\hat{S}$.

For a fixed source $(p(s),d)$, a fixed channel $(p(y|x),\rho)$, and a fixed code (F, G), we can then easily determine the average incurred distortion,

$$D_i \stackrel{def}{=} Ed_i(S^k,\hat{S}^k) \qquad 1.6.$$

and the average required cost,

$$\Gamma \stackrel{def}{=} E\rho(X^m) \qquad 1.7.$$

The information source S is merged in a codebook $(n,2^{nR})$ through the encode function F and transmitted through the channel $p(y|x)$ at a cost Γ. The channel output is decoded through the function G resulting in source estimation (or representation) $\hat{S}$, resulting in a distortion D. The maximum quantity of information transmitted through the channel, given the cost constraint Γ, is defined in terms of Mutual Information as following:

Definition 1.5 (Capacity-Cost Function): *The capacity-cost function of the channel $(p(y|x),\rho)$ is defined as*

$$C(\Gamma)=\max_{p(x):E\rho(x)\leq\Gamma} I(X;Y) \qquad 1.8.$$

The cost measure limits the quantity of information that the channel can transmit reliably. According to the Source-Channel Separation Theorem, if $H(S)\leq C(\Gamma)$, then there exist a source-channel code so that the probability of error goes asymptotically to zero. Otherwise, if $H(S)>C(\Gamma)$, then the probability of error is bounded above zero – which means that the $D>0$.[8,9] In other words, if the source entropy is greater than the channel-cost capacity, then no compression can be carried out lossless.

Intuitively, it means that when given interaction demands more information from the environment than the CNS is able to process, the probability of an accident to occur is increased. The function which gives the compression rate, for fixed distortion value D, is the Rate-distortion function.

Definition 1.6 (Rate-Distortion Function): *The rate-distortion function of the source (p(s),d) is defined as*

$$R(D)=\min_{p(\hat{S}|S):Ed_i(S,\hat{S})\leq D_i} I(S|\hat{S}) \qquad 1.9.$$

On the other hand, the function which gives the distortion value, for a fixed rate R, is the Distortion-rate function.

Definition 1.7 (Distortion-Rate Function): *The distortion-rate function of the source (p(s),d) is defined as*

$$D(R)=\min_{p(\hat{S}|S):I(S,\hat{S})\leq R} Ed_i(S|\hat{S}) \qquad 1.10.$$

We are most interested in the distortion-rate function, where the parameter $R=C(\Gamma)$; i.e. given the channel-cost capacity, we are interested in codes which can reduce the distortion value D as close as possible to its limit. The main objective of this paper is to compare different coding schemes and their respective distortion values D_i in order to measure their efficiencies.

Prompt Processing Scheme: Subitizing

Prompt information processing is represented by the following setup: An information source S emits a sequence $s_1,..,s_i,...,s_m$, of bits of information, which is compressed through a encoding function F onto a channel input sequence $x_1,..., x_i,...,x_n$ of bits of information, for $i\in T$ and $m>n$. The m-bits sequence is the perceptual information consisting of size, color, texture, length, numerousness, and so on, and the n-bits channel input sequence consists of our internal representations about the outside world. The clause that $m>n$ means exactly that the coding function is lossy compressing the environmental information into the internal representation. The n-bits channel input sequence is processed through the channel $p(y|x)$ generating an output sequence $y_1,\ldots,y_i,\ldots,y_n$, which is the semantic meaning invoked by the internal representation. The output sequence generated by the channel is decoded through decoding function G in a motor plan, $\hat{s}_1,\ldots,\hat{s}_i,\ldots,\hat{s}_k$ for $k\leq m$ (Figure 1). The pair $(F, G)^p$ is precisely our ordinary representations which ground our intuitive notion of reality. The channel has a cost limit Γ so that sequences $x_1,\ldots,x_i,\ldots,x_n$ have their length constrained – supposing that we're just interested in cases of reliable transmission.

In order to measure the average of error of the code $(F, G)^p$ some psychological experimentation is needed. Some cognitive experiments assume the following general format: A perceptual sample is showed for a short period of time – often less than one second – and then it's asked for the subject to

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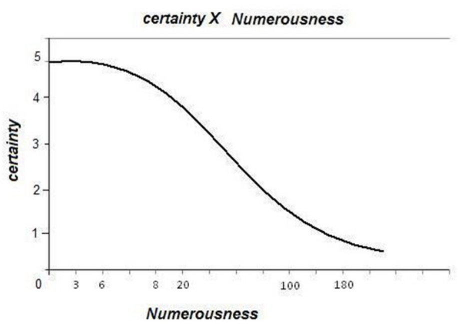
give the suitable motor answer for it – which is either voicing something or pushing a lever or executing more elaborate action plans. An example is the guessing experiments in which a given setup is quickly shown – e.g. a set of objects – and the individual has to guess the exact characteristics of the setup. Typically, the experiments' results present inconsiderable error average relative to sparse sources of stimuli – whether numerosity, extension, or velocity. But, as the source information rate is increased above a given quantity, the average of error starts to increase almost-linearly along with the source information rate. Sometimes this average of error is also expressed in terms of the Weber's Fraction, which is a constant describing of the slop of variance's growth recta related to the increasing of the quantity of information[1] – as the variance increases the error average does as well. The Weber's Fraction, for numerical processing is around 12%,[10] for size-constancy processing it is around 4%, and for the object's speed and trajectory processing it is between 5%-10%.[11] Still other perception's modalities, such as color hues,[12-17] show the same trade-off between the source information rate and error average.

The trade-off between the source information rate and the average of error can be appreciated in the number processing case. In the number guessing experiment, a setup containing a given number of entities is shown for a short period of time – often less than one second – and the subject has to guess the setup's numerosity. The subject's test performance gives rise to two numerical processing phenomena; *subitize* and *estimation.* In the former condition, one is able to subtly recognize the set's numerosity up to around 3 or 4 elements while, in the latter condition, only an estimation is possible.[18,19,40] As the term "subitizing" suggests, it occurs when the individual subtly recognizes the set's numerosity as rapid as 40-100ms/item, effortless, and very accurate – practically error-free. On the other hand, for setup's numerosity greater than 4 only estimations with some degree of uncertainty are possible, which means that the average of error is bounded above zero.

Kaufman et al represented the subjects' number guessing performance through the trade-off between uncertainty and the source information rate (Graphic 1).[18] The certainty axis is divided in 6 degrees, where 5 means complete certainty and 0 means complete uncertainty. Notice, that at 4 or 5 objects, there is almost complete certainty while it brusquely decreases after 6 objects. Graphic 1 shows clearly the almost linearly increasing of the average of error, after a given value, along with the source information rate increasing. Therefore, if few objects compose the setup, the visual representation achieves the right magnitude with high certainty; i.e. $D_i \approx 0$. Otherwise, for large setup's numerosity, the average of error is bounded above zero, $D_i > 0$. In summary, the code $(F, G)^p$ compresses the m-bits perceptual sequence in an n-bits channel input sequence, which consists of our internal representations about the outside world. As the channel-cost capacity limits the number of bits reliably transmitted, the perceptual sequence's bits are lossy compressed in the channel input code words. The compression carried out by the code $(F, G)^p$ is a kind of all-purpose one, for even in the situations in which only numerosity is interesting, color information, for example, cannot be stripped out from the representations. For this reason, the perceptual sequence's bits interact with each other so that a setup with exceeding color information disrupts the number processing, for example.[18] The uninteresting information is called redundancy and the prompt processing scheme doesn't seem to be a good code to handle specific situations. But why has nature endowed us with such a code? The reason seems to be that the $(F, G)^p$ code is a good code, on average, over many different situations. When the average distortion D is calculated for whole set U of Hamming-like distortion functions, $d_i(S, \hat{S})$, the expected value $E(U)=\frac{1}{2^{|S|}}\sum\sum_1^{2^{|S|}} D_i$ results in a tolerable value – i.e. it keeps the organism alive in most cases.



Graphic 1: Certainty versus numerousness.

Working Memory Scheme: Biological Recoding

The main idea of the previous discussion was that the prompt coding scheme is a good one when handling a variety of situations, but it is not an optimal code when handling specific tasks – i.e. it is a good source-channel code averaging over all Hamming-like distortion measures $d_i(S, \hat{S})$, but it is a bad one for a subset of them. For specific situations, where just some specific bits are relevant, a different coding function would be better.

This time I will examine how the working memory's role in cognitive tasks fits into our previous theoretical model. The working memory is basically a memory system needed for executing complex motor tasks when the essential cues are not present in the environment at the time of the response.[20] The system, in different ways, seems to help the performance of cognitive tasks. I will interpret the working memory as an encoder which employs different codes $(F, G)^w$ according to different distortion measures $d_i(S, \hat{S})$.

The term 'working memory' refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language compression, learning, problem solving, and action planning.[21] The working memory has two broad functional characteristics; maintenance and manipulation of information. According to the

[1]The guessing performance's uncertainty can be conceptualized through different notions; for example, either in terms of variance, or entropy, or simply as a conditional distribution

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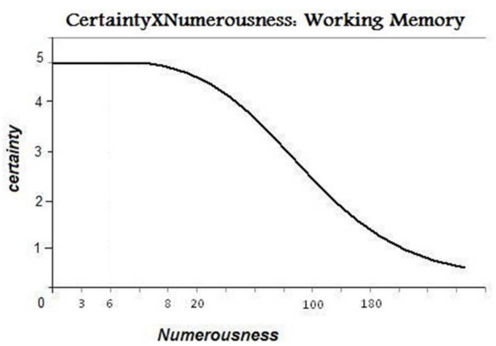
multicomponent model,[22,23] the information maintenance is putatively carried out by three distinct systems; the phonological loop, the visuospatial sketchpad, and the episodic buffer. The first two are modal subsystems, respectively, for auditory and visual information, while the last is a multimodal integration subsystem. Still each maintenance system has two functional distinctions; the passive storage and active rehearsal of information. The passive storage retains the information temporarily and it is subject to loss by decay or interference over time. The active rehearsal of information tries to simulate the retained information so as to keep it in mind – e.g. rehearsal would correspond to the common strategy of sub vocally repeating the sequence of digits to oneself. The other broad functional characteristic, manipulation of information, corresponds to the central executive, which is responsible for recoding the information in a new format – such as when one sub vocally repeats some sequence of digits according to a specific format. Neurological evidence suggests that the anterior regions of the cortex – such as inferior frontal cortex (BA 44; Broca's area) and premotor cortex (BA 6) – are responsible for rehearsal and manipulation, while posterior regions of the cortex are responsible for storage – such as inferior and superior parietal cortex (BA7/40) and right inferior parietal cortex (BA 40).[24-28]

Even if the temporary storage and manipulation roles can help in cognitive tasks separately, we will focus on the cases in which they seem to work together in order to recode the perceptual information.[20,22,23,29] The preprocessed information is retained in one of the storage systems and then it is recoded by the manipulation system. For example, for the case in which one is interested in the setup's numerosity, the subject can recode the setup's numerosity in terms of "chunks" so as to surmount the prompt processing limit.[30-34] Therefore, if the processing of numerousness was limited to around 3 or 4 objects (subitizing), then by using working memory one is able to increase this number to around 7, with very low average of error (Graphic 2) – without counting! The encoder's role is viewed as an endeavor to deploy different source-channel codes $(F, G)^w$ in order to reduce distortion value D_i according to every specific i – remember that the index i is given by typical sequence (situation) occurring. The new mental representation (channel input) generated by the working memory is very poor concerning color, size or texture information, but it is much more informative about numerical information – it is a better code for handling redundancy.



Graphic 2: Certainty *versus* numerousness by using working memory.

If it is plausible to interpret the working memory as an encoder, then the information kept in it should be of a preprocessed kind. Neuropsychological evidence offers support for the independence between the working memory's information and the semantic content currently retrieved through it. Among this evidence is the fact that similarities in semantic content currently retrieved through a set of stimuli are irrelevant for the acuity with which these stimuli are kept in working memory. For example, if one were given a list of words, such as "map" "tap" "lap" "flat" and so on, it would be difficult to remember all those words because the stimuli displays similar pattern. On the other hand, if one were given a list of words, such as "house" "home" "abode" "apartment" someone would not have as much of a problem remembering even if the semantic content is about the same. This is because working memory functions at a preprocessed level not taking into consideration the semantic content.[35] Still, the concurrent modal information tends to disrupt different modal information kept in working memory. There is a reduction in recalling lists of visually presented items brought about by the presence of irrelevant spoken material. The spoken material's semantic content is completely irrelevant, with unfamiliar languages or noisy sounds being just as disruptive as meaningful words in one's own language. These results are interpreted under the assumption that disruptive spoken material gains obligatory access to working memory.[36]

Even if the working memory allows the brain to surmount its limits of prompt processing, it doesn't get far enough. This system appears to be strikingly limited in capacity, and can only store a small amount of information for short periods of time – it's around three items for not more than three seconds--in the number processing case.[30-34] On the other hand, working memory's representation is still structured with the same prompt processing code's properties – i.e. even if it privileges some kind of information, say numerosity, it cannot preclude the other kind of information, such as colors, forms, and so on. For example, if a dense colorful setup is presented, it causes the numerical capacity of visuospatial sketchpad, which is generally estimated to be about 4 items, to decrease.[30,34] These results generalize the working memory's limits for the setup's complexity, rather than for just the number of objects.[35]

The Cultural Strategy: The Employment of Symbols

The working memory, as previously mentioned, is an encoding system which stores information and recodes it. The problem with this system is that it is severely limited in storage capacity. Additionally, the working memory code is too costly for optimally handling large amounts of information; its overload causes severe disruption to many cognitive tasks. A new and less costly format is the channel code $(F, G)^S$,[2] which represents symbolic language as another coding scheme. The symbolic language coding scheme has at least two advantages in comparison with the internal representation schemes. First, it is a cheaper and more efficient channel code than the internal representation

[2]A similar interpretation, in terms of two mental calculation systems, has been offered by Dehaene.[37]

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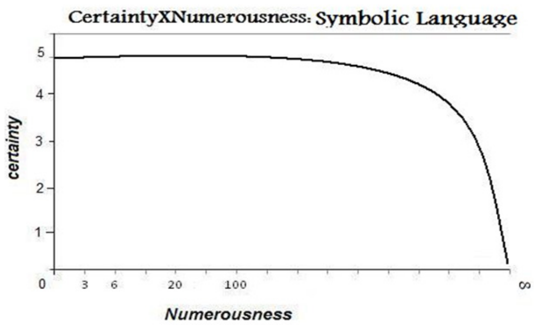
schemes and, second, it liberates the working memory to help in learning, problem solving, and planning tasks. By using a more efficient code, much more information can be reliably transmitted, which ends up improving drastically the system's control upon the environment.

Efficiency and cost: The three-object prompt processing limit can be interpreted as the channel-cost capacity. An efficient channel code should achieve the smaller error rate by compressing the source information in code words that don't exceed the complexity expressed by that setup. To compare two codes' efficiency one should pay attention to its average of error on the cognitive tasks. By comparing the internal representation codes' performance with the symbolic performance in numerical tasks, one can see the huge difference in efficiency (Graphic 3).



Graphic 3: Certainty versus numerousness by using symbolic language.

The graphic is, to some extent, speculative because mathematical skills based on symbolic language mastery vary according to cultural factors such as training, educational system efficiency, and so on. At least two groups of evidence support the interpretation of the symbolic language as a channel coding scheme; (*i*) the symbolic language deficit increases the error rate in retrieving the right numerical magnitude; and (*ii*) the symbolic systems' evolution proceeds seems to be constrained by brain processing cost-capacity.

(i) The symbolic language deficit increases the error rate in retrieving the right numerical magnitude. There is a correlation between the bloom of the mathematical skills and mathematical language competence. The burst of conceptual and interactive mathematical skills with which to handle quantities beyond the subitizing's and working memory's numerical capacity is concomitant with the numerical language acquisition. The ability to count and handle larger numerosities rises in children around $3\frac{1}{2}$ years old just when numerical linguistic devices start being mastered. On the other hand, evidence from Amazonian Indigene groups have supported the thesis that language is a condition of possibility for exact representation of numerosities beyond subitizing quantities. The group's individuals, whose language misses linguistic devices for quantities larger than 3-or-4 objects, have shown only an ability to estimate over larger quantities. Neuropsychologists have found that disorders in number representation frequently are accompanied by disorders in language. Patients with brain damage in areas typically associated with language faculties have shown a severe impairment with exact numerical processing of larger quantities. These same patients, however, still keep their capacity to exactly represent quantities up to three objects and to estimate over larger quantities.[37]

(ii) The symbolic systems' evolution proceeds seem to be constrained by brain processing cost-capacity. As human interaction routines require the processing of larger quantities, it increases the demand for channel code bits. Different numerical notional systems have different costs, which eventually obligate us to change from one numerical notational system to another according to the increase of the demand. The complexity expressed by the around-three-objects representation can be interpreted as standing for the channel-cost capacity limit, which doesn't mean that this limit is the around-three-objects numerosity, as it contains figurative information as well.

Probably, the first numerical notational system used consisted of bundles of sticks paired one-to-one with the setup's objects (Figure 2). It was the least efficient numerical notation, because its only advantage was that of keeping the informational content out of the ever changing environment, which saves short or long-term memory demand. However, as the number of sticks increases along with the set of objects' numerosity the bundle-of-sticks coding scheme meets the same subitizing's and working memory's limits. Therefore, the bundle-of-sticks numerical system is a costly channel code to process quantities larger than fifteen or twenty objects. Looking at the code's redundancy is another way to assess the code's efficiency. Notice that every stick can be permutated without changing the code's information, which means that the code uses much more bits than necessary to encode a given amount of information.

Figure 2: Bunch-of-sticks number system.

The second, the naming-summation numerical system is a channel code category under which, for example, are the Egyptian and Roman number systems, characterized by the employment of naming quantities and summation strategies. The notational marks are for numerical magnitudes and their repetition means their summation.[38] The marks retrieve numerical facts stored in long-term memory whose meaning is provided

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by inborn numerical skills or constructed by combining them. For example, the Egyptian inscription of the number 543 is HHHHHTTTTUUU, where the symbols H, T, and U denote the powers 100, 10, and 1, respectively. Through the use of the naming-summation numerical system the numerical information can be compressed in shorter code words than those provided by the bundle-of-sticks system (which is coextensive with the subitizing's and working memory's limits) – the Roman numerical system, which uses subtraction notations as well, produces even shorter compressions. However, as the permutation test indicates, the representation provided by the naming-summation numerical systems still contains too much redundancy; e.g. the code words HHHHHTTTTUUU and HHUHUHTTUHTT express the same numerical quantity. Even though the naming-summation numerical system permits us to process exact quantities in the hundred's magnitude, it becomes too costly to process numerosities around the thousand's magnitude, meeting the subitizing's and working memory's limits.

The third example is the multiplicative numerical system - e.g. Chinese number system.[38] The multiplicative numerical system is also based on underlying additive and naming principles, but a supplementary multiplicative principle allows for suppression of the cumbersome repetitions of the symbols belonging to the same rank. Different symbols for each unity (*u1,u2,...,u3*) are introduced. The Chinese 543 is therefore written in the form, *u5Hu4Tu3*. Although the multiplicative system uses five different symbols instead of three needed in hieroglyphic Egyptian, it makes it possible to compress the numerical information in shorter code words. However, as some permutation is still permitted – *u5Hu4Tu3* means the same as – *u4Tu5Hu3* the representation provided by this category of notation contains redundancy.

The last numerical system is the positional numerical system – the Arabic Number System.[38] This system was developed some time in the first half of the sixth century A.D. in India, from whence it spread more or less rapidly to the whole world through the Arabic people. The system uses only 10 symbols, the same former system's operations, and the rank of the units abstractly symbolized by the position occupied by these units in the code word. The Arabic numerical system encodes quantities in the usual way, as we know it, and produces very short compressions of huge quantities – e.g. 10^{80} , which is approximately the number of atoms in the entire observable universe. It also provides us with powerful algorithms by which different quantities and relations are compressed in shorter code words – equations. These algorithms can be viewed as a whole class of encoding functions producing the shortest code words possible. As easily noticed, permutation among the symbols are not permitted without changing the encoded information.

Although the above discussion has been restricted to the processing of quantities, the same interpretation can be applied to different dimensions of perceptual information processing. Therefore different areas of applied mathematics are connected with different cognitive processing limits; e.g. geometry and size-constancy processing, differential calculus and object's speed and trajectory processing, and so on. The interpretation also seems to give an explanation to the intuition "simple theories are the best theories", for the simple theories' costs are smaller, which decreases the probability of error. It's by no mere chance that much of the mathematician's work consists of, by exploring the isomorphism among different structures, finding simpler ways in which to solve a problem. However, it doesn't always mean that complex theories can be compacted into simple (low cost) representation. In fact, according to the source coding theorem, the lower bound compression is the $R(D)$, which is $R(0)=H(X)$. Therefore, as long as one looks for less lossy representations, the code words' cost inevitably is to increase.

Representations Stand for What?

The representational interpretation of the internal experience and the symbolic language's role has dominated the occidental thought at least since Plato. The general idea of this line of thought seems to be grasped through the Varela et al. words:

> "[…] that the world is *pre-given*, that its *features* can be specified prior to any cognitive activity. Then to explain the relation between this cognitive activity and a pre-given world, we hypothesize the existence of mental representations inside the cognitive system (whether these be images, symbols, or sub-symbolic patterns of activity distributed across a network does not matter for the moment)."[39]

In the representational interpretation, the particularities of a given representation – such as colors, extension, or commutativity – stand for real properties from the outside world and it is the relation of correspondence or adequacy, with its reference to the outside world that makes one representation better than another.[3] On the other hand, in the channel code interpretation of the representation's role, a code's intrinsic characteristics, for example, encoding light as colors or as wave lengths, has nothing to do with source information, all that matters is the source's and code's complexity. As we have seen, these particular coding aspects have rather a lot to do with channel and its cost, and not with the source itself. Speculatively, if the brain-cost capacity were greater (or infinity) than that suggested by cognitive experiments, the employment of symbolic language would be unnecessary.

What does it mean to say source and code complexity? The intuitive way to understand this complexity is in terms of the degrees of freedom of the system's behavior or the degrees of freedom through which a system can affect another one. Mathematically, any system can be conceptualized as a set of variables and its degrees of freedom as a distribution of probability. If so, the Shannon Entropy, which is a function of the distribution of probability, emerges as a suitable measure of

[3]It is worth noting that in the representational interpretation, the belief that simple theories are better has, in principal, no clear explanation.

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complexity in terms of the minimum bits necessary to describe unequivocally the system behavior.[4; 8,40,41] More importantly, the main purpose of a code is to convey the source's complexity as reliably as possible. However, very different codes can display the same complexity and their intrinsic characteristics will depend exclusively on the channel's nature. But how can we evaluate the code's performance? This is a very important question.

To evaluate the code's performance, one has to measure the distance between the source information and the processing information, which is properly the source representation. This distance is measured according to a distortion measure whose definition depends on the system's purpose. As we have said before, as the CNS is understood as a control system, the distortion measure has to be one that grasps this controlling dimension. In our model, the distortion measure is a Hamming-like distortion that we call Accident Function, $d_i(S, \hat{S})=\left\{\begin{matrix} 0 \text{ if } s=\hat{s} \text{ e } s \in \hat{S}_i \textit{ ou } s \neq \hat{s} \text{ e } s \notin \bar{\bar{S}}_i \\ 1 \text{ if } s \neq \hat{s} \text{ } e \text{ } s \in \bar{\bar{S}}_i \end{matrix}\right\}$. The accident function interprets, as an error, the decoding which results in accident. Therefore, the symbol "=" does not represent "equals" or "equivalent" but represents successful action – the symbol "≠" is for unsuccessful action. Therefore, if two coding schemes result in the same source representation (action plans), they will be equivalent for communication purposes. The perspective seems to be in agreement with one of the older philosophical insights; that we cannot compare the reality with subjective or symbolic representation. However, all the time, we compare and test the motor plans and empirical experiments resulting from these coding schemes. When a given code directs us to a successful motor plan, we say that "it represents the reality". Putting these two ideas together we get to the following statement: Our epistemology (coding schemes) can be diverse, but our ontology (successful interaction) is unique.

CONCLUSION

I have been discussing, broadly, different paths taken by an organism to better perform cognitive tasks. In this interpretation, these "paths" are understood as different coding schemes through which information is processed by the Central Nervous System. Two main aspects concerning the coding schemes' performance were pointed out. These are the coding scheme's cost and its ability to handle with redundancy. We distinguished among three coding schemes to which the organism resorts: the prompt processing, working memory, and the symbolic coding scheme. The prompt processing scheme seems to be the better code on average; however, a bad one for specific tasks. The working memory coding scheme seems to be better than the former one, but still too costly to perform specific tasks optimally. The symbolic scheme seems to be the cheapest and the more dynamic one for handling redundant information. The coding scheme metaphor serves to explain the old philosophical insight that simple theories are better theories and to mark a division between the epistemological domains as diverse versus the ontological domain as unique.

[4]Shannon Entropy is not the only measure of complexity. The Kolmogorov-Chaitin complexity is also a measure of complexity and both measures are mathematically related.[3,16,29]

CONSENT STATEMENT

Authors obtain written informed consent from the patient for submission of this manuscript for publication

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Review

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Expected Agreement Coefficient for Norm-Referenced Tests With Classical Test Theory

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ABSTRACT

There are two types of agreement coefficients for psychological test scores: norm-referenced and criterion-referenced agreement coefficients. These coefficients were derived within the framework of generalizability theory that is known for its theoretical and practical complexities. Under the framework of classical test theory, the paper derived the norm-referenced agreement coefficient. This derivation was based on the assumption of randomly equivalent test forms. The resulted expected agreement coefficient was different from its counterpart in generalizability theory. However, the estimators of this norm-referenced agreement coefficient were equal under the two frameworks to coefficient alpha reliability.

KEYWORDS: Norm-referenced; Agreement coefficient; Coefficient alpha; Classical test theory.

INTRODUCTION

Psychological tests can follow two frameworks for interpretation and uses of their results: Norm-referenced and criterion-referenced. With norm-referenced interpretation and uses, investigator's interest focuses on the relative ordering of examinees with respect to the performance for the norm group which the examinee is associated.[1] In generalizability theory framework, relative error scores variance is defined as the expected squared difference between an examinee's observed deviation score (from examinee's true score) and the associated group's observed deviation score. On the other hand, criterion-referenced interpretation suggests that the investigator's interest focuses on absolute interpretations of scores and absolute error scores variance.[1-3] Relative error scores variance is defined as the expected squared difference between an examinee's observed deviation score and the examinee's true score.[4]

Since the first distinction between norm-referenced and criterion-referenced interpretations of test results, many researchers including Glaser and Nitko[5] and Popham and Husek[6] argued that reliability coefficients in the classical test theory are appropriate for norm-referenced tests. These coefficients (such as KR-20[7] and coefficient alpha[8]) depend on the relative standing of an examinee on a norm group.[9-10]

Kane and Brennan[11] introduced a very useful general agreement function that is used to summarize different existing agreement coefficients for different uses and interpretations of test scores. Using this general agreement function, Kane and Brennan[10] defined the norm-referenced expected agreement coefficient for norm-referenced tests (called generalizability coefficient) with generalizability theory framework. Using the general linear model for design (all examinees take same set of items) in generalizability theory for examinee's observed score on each item, , on a sample of items, Brennan and Kane derived the agreement coefficient for norm-referenced interpretation and showed that the estimator of this coefficient is equal to coefficient alpha developed by Cronbach.[8]

The concept of expected agreement and its derivation method is very useful to un-

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derstand test results and enhance its interpretation and uses.[12] It helps to differentiate examinees' error scores and accordingly examinees' true scores and test score reliability. Brennan[1] explained that norm-referenced agreement coefficient is associated with relative error scores whereas criterion-referenced agreement coefficient is associated with absolute error scores. The two types of error scores differ in their definition and implication when estimating and interpreting test score reliability.

The current application and utilization of the expected agreement is limited to generalizability theory frameworks. However, generalizability theory involves both theoretical and practical complexities.[1] It is based on mixture of concepts of variance components in analysis of variance and concepts of classical test theory. Similarly, the estimation of the expected agreement coefficient requires estimation of mean squares.[1,13]

On the other hand, classical test theory is based on simpler concepts and estimation methods that are appreciated by many practitioners.[4] The advantages and application of expected agreement are not yet introduced within classical test theory. One possible reason behind delaying usages of expected agreement coefficient in classical test theory might be traced to its conventional definition of equivalent test forms.

The paper introduced the expected agreement for norm-referenced interpretations of test scores within classical test theory framework. The paper presents the context and assumptions of randomly equivalent test forms that are necessary to develop the expected agreement coefficients. The paper derived the expected agreement/reliability coefficient for norm-referenced tests utilizing the general agreement coefficients pioneered by Kane and Brennan.[11] Moreover, the estimator of this expected agreement coefficient was outlined.

METHOD

Procedure

The paper used the procedure outlined by Kane and Brennan[11] for deriving the expected agreement between two randomly selected instances of a testing procedure. The procedure assumes that the instances or tests are randomly selected from a universe of possible instances, which support the assumption that the expected distribution of outcomes for the population is believed to be the same for each administration of the testing procedure. The agreement function, $a(S_{pi}, S_{pj})$ defines the degree of agreement between any two scores of an examinee on two testing procedures, S_{pi} and S_{pj}. This agreement function can take any form as long it satisfies three conditions:

(1) $a(S_{pi},S_{pj})\geq 0$,

(2) $a(S_{pi},S_{pj})=a(S_{pj},S_{pi})$, and

(3) $a(S_{pi},S_{pi})+a(S_{pj},S_{pj})\geq 2a(S_{pi},S_{pj})$.

Two general agreement indices of instances for the testing procedure are defined: One is corrected for chance while the other is not corrected. The index of agreement which is not corrected for chance is:

$$\theta = \frac{A}{A_m}$$

The term A is the expected agreement given by $A=E_{p,I,J}a(S_{pI},S_{pJ})$, where the expectation is taken over the population of examinees and over pairs of tests that are independently sampled from the universe of tests and administered to the same population of examinees. The term A_m is the expected agreement between the instance of the testing procedure and itself, $A_m=E_{p,I}\, a(S_{pI}, S_{pI})$, where A_m represents the maximum value of A. A is equal to A_m when each examinee in the population has the same score on every test. Kane and Brennan noted that A_m corrects the problem of the dependence of on the scale of $a(S_{pI}, S_{pJ})$.

The index of agreement which is corrected for chance is

$$\theta_c = \frac{A-A_c}{A_m-A_c}$$

where term A_c quantifies the agreement between the two instances of the testing procedure that is due solely to chance. It is defined as the expected agreement between the score, S_{pi}, for a random selected examinee p on one test and the score, S_{qj}, for another independently sampled examinee q on an independently another sample test. That is.,

$$A_c=E_{p,q,I,J}\, a(S_{pI},S_{qJ})=E_{p,I}\, a(S_{pI})E_{q,J}\, a(S_{qJ}).$$

Also, Kane and Brennan[11] define the expected disagreement or loss as the difference between the maximum expected agreement and the expected agreement,

$$\sigma^2(\epsilon) = L = A_m - A.$$

This expected loss gives the error score variance associated with the expected agreement function.

RESULTS

In order to derive the expected agreement coefficient within the context of classical test theory, we need to first introduce the concept of randomly equivalent test forms instead of the classical equivalent test forms. Randomly equivalent test forms is evident when the test developer is able to build a very large or infinite number of different test forms from a large pool of items measuring the psychological construct. Hence, test forms of equal size are considered randomly equivalent forms if each is sampled randomly and independently from the large pool of items. These test forms are not expected to have equal mean scores nor equal variance. However, examinees error scores from these randomly equivalent test forms are expected

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to be uncorrelated. Moreover, it is assumed that any test form is administered to a large sample of examinees that are randomly selected from the population of examinees.

In order to derive the expected agreement/reliability of test scores on test form (say form X), we need to hypothesize that this test form and another hypothesized form (say form Y) are randomly equivalent test forms with different items but equal in terms of size (form X with I items and form Y with J items). Let us refer form X as a reference test form and the other test form (form Y) as a hypothesized test form. These two forms are then administered to the same sample of examinees of size N.

For a norm-referenced test where the decision is based on the relative position of examinees to their peer examinees, the agreement function is defined as the expected product of relative distance of the observed average scores ($\bar{X}_p$ and $\bar{Y}_p$) on two randomly equivalent test forms from the associated mean score for items on each test form (T_I and T_J) over all examinees.

$$A(r) = E_{P,I,J}\,(\bar{X}_p - T_I)(\bar{Y}_p - T_J) = \frac{1}{n^2}\, E_{P,I,J} \sum_i\sum_j (X_{pi}-T_i)(Y_{pj}-T_j)$$
$$= E_{P,I,J}\, \overline{(X_{pi}-T_i)(Y_{pj}-T_j)}$$

where the expectation is over infinite randomly equivalent test forms of X and Y; each with equal number of items from the domain, over infinite randomly independent samples of N examinees from the population, and $E_{P,I,J}\overline{(X_{pi}\text{-}T_i)(Y_{pj}\text{-}T_j)}$ is the expected mean pair wise covariance of items on X with items on Y with relative to their individual item mean scores.

For the reference test form X, $E_{P,I}\overline{(X_{pi}-T_i)(X_{pi'}-T_{i'})}$ represent the expected mean pair wise covariance of distinct items on X (i≠i') with relative to their mean scores. Similarly, let $E_{P,J}\overline{(Y_{pj}-T_j)(Y_{pj'}-T_{j'})}$ have similar definition for items on test form Y. Because of randomly equivalent test forms,

$$E_{P,I,J}\overline{(X_{pi}-T_i)(Y_{pj}-T_j)} = E_{P,I}\overline{(X_{pi}-T_i)(X_{pi'}\text{-}T_{i'})} = E_{P,J}\overline{(Y_{pj}-T_j)(Y_{pj'}-T_{j'})}$$

Hence, the expected agreement function, *A(r)* , becomes

$$A(r) = E_{P,I}\overline{(X_{pi}-T_i)(X_{pi'}-T_{i'})} = \frac{1}{n(n-1)}\, E_{P,I}\sum\sum_{i\neq i'}\overline{(X_{pi}-T_i)(X_{pi'}-T_{i'})}$$

By simple algebra, *A(r)* becomes,

$$A(r) = \frac{1}{n(n-1)}\,[n^2 E_{P,I}(\bar{X}_p - T_I)^2 - E_I \sum_i E_p (X_{pi}-T_i)]\,,$$

where $T_I = E_I \sum_i T_i$.

This expected agreement function gives the true score variance for norm-referenced tests, $\sigma^2(T_r)$. The maximum expected agreement for norm-referenced testing is,

$$A_m(r) = E_{P,I}(\bar{X}_p - T_I)(\bar{X}_p - T_I) = E_{P,I}(\bar{X}_p - T_I)^2$$

The expected agreement for norm-referenced testing due to chance is,

$$A_c(r) = E_{P,Q,I,J}(\bar{X}_p - T_I)(\bar{Y}_q - T_J) = E_{P,I}(\bar{X}_p - T_I)\, E_{Q,J}(\bar{Y}_q - T_J)$$
$$= E_{P,I}\left(\frac{1}{n}\sum_i X_{pi} - \frac{1}{n}\sum_i T_i\right) E_{Q,J}\left(\frac{1}{n}\sum_j Y_{qj} - \frac{1}{n}\sum_j T_j\right) = 0,$$

because $E_P(X_{pi}) = T_i$ and $E_Q(Y_{qj}) = T_j$. Hence, the norm-referenced agreement coefficient is,

$$\theta(r) = \theta_c(r) = \frac{\frac{1}{n(n-1)} E_{P,I}\sum\sum_{i\neq i'}(X_p - T_i)(X_{pi'} - T_{i'})}{E_{P,I}(\bar{X}_p - T_I)^2}.$$

$$\text{or } \theta(r) = \theta_c(r) = 1 - \frac{\frac{1}{n(n-1)}\left[E_I \sum_i Ep(X_{pi} - T_i)^2 - nE_{P,I}(\bar{X}_p - T_I)^2\right]}{E_{P,I}(\bar{X}_p - T_I)^2}.$$

This coefficient can be also written as,

$$\theta(r) = \theta_c(r) = \frac{n}{n-1}\left(1 - \frac{E_I \sum_i E_p (X_{pi} - T_i)^2}{n^2 E_{p,I}(\bar{X}_p - T_I)^2}\right).$$

This result suggests that the correction for chance agreement has also no effect on the norm-referenced agreement.

The expected loss associated with the norm-referenced agreement coefficient is,

$$L(r) = A_m(r) - A(r) = \frac{1}{n(n-1)}\left[E_I \sum_i E_P (X_{pi} - T_i) - nE_{P,I}(\bar{X}_p - T_I)^2\right]$$
$$= \frac{1}{n(n-1)}\, E_{P,I}\sum_i((X_{pi} - T_i) - (\bar{X}_p - T_I))^2$$

which equals the appropriate error score variance for norm-referenced tests, $\sigma^2(\epsilon_r)$.

This error score variance is similar to the relative error score variance identified by Brennan and Kane[2] using Generalizability theory. This quantifies the expected squared difference between each examinee's observed deviation score from the test average score and the deviation of an examinee's true score from the test average score on the domain of items.

ESTIMATION

The components of all expressions of the expected agreement/reliability coefficients have the form of expected value of some terms over different random sets of items from the domain of items and over different random samples of examinees from the population of examinees. The sample counterparts of these terms can be used to estimate these expected values.

The expected norm-referenced agreement/reliability coefficients can be estimated by collecting data from adminis-

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tering one test form of n items to a representative sample of N examinees. If we substitute $(\bar{X}_p)$, T_i and T_I by their sample counterparts, $\bar{x}_p = \frac{1}{n}\sum_i x_{pi}$, $\bar{x}_i = \frac{1}{N}\sum_p x_{pi}$, and $\bar{x} = \frac{1}{n}\sum_i \bar{x}_i = \frac{1}{N}\sum_p \bar{x}_p$ respectively, the estimator of the expected agreement coefficient for norm-referenced test is,

$$\hat{\theta}(r) = \frac{\frac{1}{n(n-1)}\sum\sum_{i\neq i'}\hat{\sigma}^2_{ii'}}{\hat{\sigma}^2(\bar{x}_p)} = 1 - \frac{\frac{1}{n(n-1)}\left[\sum_i \hat{\sigma}^2(x_{pi}) - n\hat{\sigma}^2(\bar{x}_p)\right]}{\hat{\sigma}^2(\bar{x}_p)}$$

$$= \frac{n}{n-1}\left(1 - \frac{\sum_i \hat{\sigma}^2(x_{pi})}{n^2\hat{\sigma}^2(\bar{x}_p)}\right)$$

The associated loss is,

$$\hat{L}(r) = \frac{1}{n(n-1)}\left[\sum_i \hat{\sigma}^2(x_{pi}) - n\hat{\sigma}^2(\bar{x}_p)\right],$$

Which gives the estimator of the relative error score variance for norm-referenced test

In these equations,

$$\hat{\sigma}_{ii'} = \frac{1}{N-1}\sum_p (x_{pi} - \bar{x}_i)(x_{pi'} - \bar{x}_{i'}),$$

$$\hat{\sigma}^2(x_{pi}) = \frac{1}{N-1}\sum_p (x_{pi} - \bar{x}_i)^2,$$

$$\hat{\sigma}^2(\bar{x}_{pi}) = \frac{1}{N-1}\sum_p (\bar{x}_p - \bar{x})^2.$$

DISCUSSION AND CONCLUSION

The paper derived the expected agreement coefficient for norm-referenced tests using classical test theory framework under the assumption of randomly equivalent test forms as replacement of the conventional equivalent test forms. The estimators of the resulted coefficient proved itself to be equal to coefficient alpha for Cronbach[8] that was derived under different assumption of essentially tau-equivalent test form.

This result supports what Glaser and Nitko[5] and Popham and Husek[6] argued that reliability coefficients in the classical test theory such as coefficient alpha and KR-20 are appropriate for norm-referenced tests. The error scores associated with coefficient alpha is the relative error score variance that is defined as the difference between individual examinee's performance and the performance of his/her peers who took the test.

The estimation of the expected agreement coefficient for norm-referenced tests can use either unbiased or biased estimators of its terms. It can be easily showed that if the biased estimators of the terms in the above equations are used, they would give identical estimates of the expected agreement coefficient for norm-reference tests. However, the estimation of the error score variances and the true score variance, however, are affected by whether the unbiased or biased sample variances are used (The unbiased estimators are preferred).

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Accessibility of Chronic Pain Treatment for Individuals Injured in a Motor Vehicle Accident

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ABSTRACT

Background: Chronic Pain (CP) is a pervasive problem that can drastically lower one's quality of life. Therefore, it is imperative that CP sufferers receive appropriate intervention. At the Michael G. DeGroote Pain Clinic of Hamilton Health Sciences, assessed individuals are either recommended or not recommended for admission into the four-week interdisciplinary pain management Program. Despite receiving recommendation for admission, many are denied insurance coverage for unspecified reasons and cannot undergo required treatment.
Purpose: To investigate if there were clinically significant differences in demographics and pain-related measures between individuals granted *versus* denied insurance coverage for CP treatment.
Methods: Data were collected from 99 patients recommended for admission into the Program. Pain-related questionnaire scores and demographic information were compared between patients denied coverage (n=49) and patients granted coverage (n=50) using two-way MANOVA and Pearson chi-square tests of independence.
Results: Findings on pain-related variables revealed scores that warranted clinical attention in all patients. The majority of measures revealed no patient need-related differences between groups. Pain Stages of Change Questionnaire (PSOCQ) contemplation scores between groups were significantly, yet not clinically, different. Consistent with the literature, Tampa Scale for Kinesiophobia and PSOCQ pre-contemplation scores were significantly higher in males than females.
Conclusions: As hypothesized, these findings strongly support the hypothesis that there are no clinically meaningful differences between groups, suggesting that the separation of groups established by insurance companies was artificial, and not based on any tangible clinical factors. It also implies that insurance companies are likely provisioning funds on systems-related rather than patient need-related criteria.

KEYWORDS: Chronic pain; Insurance coverage; Interdisciplinary pain management.

ABBREVIATIONS: CP: Chronic Pain; PSOCQ: Pain Stages of Change Questionnaire; OHIP: Ontario Health Insurance Plan; FSCO: Financial Services Commission of Ontario; MIGs: Minor Injury Guidelines; HiREB: Hamilton Integrated Research Ethics Board; PDI: Pain Disability Index; BPI: Brief Pain Inventory; PCS: Pain Catastrophizing Scale; PRIME-MD PQ: Patient Questionnaire of the Primary Care Evaluation of Mental Disorders; PQ: Patient

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Questionnaire; PSOCQ: Pain Stages of Change Questionnaire; CPAQ-R: Chronic Pain Acceptance Questionnaire-Revised; TSK-11: Tampa Scale for Kinesiophobia-11; CAS: Clinical Anxiety Scale; CES-D: Center for Epidemiological Studies-Depressed Mood Scale; BDI: Beck Depression Inventory.

INTRODUCTION

Chronic Pain: An Overview

Chronic Pain (CP) is characterized as pain persisting for more than 6 months in the absence of ongoing nociceptive stimuli.[1-3] In Canada, CP affects approximately 11% to 29% of the general population.[4-6] This is problematic, as CP is often debilitating: as many as 60% of individuals with CP incur loss of income, eventual job loss or reduction in professional responsibilities.[7] Tang[8] reports that individuals living with CP have worsened quality of life and double the risk of suicide compared to those without CP. At the societal level, CP produces substantial economic burden in Canada, rivaling costs of cancer and heart disease combined.[7] Direct CP healthcare costs amount to approximately $6 billion per annum, while indirect costs amount to $37 billion per annum (e.g., loss of productivity, job loss, sick days, etc.).[7]

The Effectiveness of Interdisciplinary Chronic Pain Management

Due to the high economic and personal costs of CP, it is imperative that CP sufferers receive effective intervention.[3,9] Many pain management strategies can be utilized (e.g., monotherapy, multidisciplinary, interdisciplinary etc.) to reduce CP symptoms and increase overall quality of life.[10-12] The application of one treatment in isolation (e.g., monotherapy) is often ineffective, as it addresses only one aspect of CP (e.g., biological factors) offering little pain relief.[13] In comparison, interdisciplinary pain management has been shown to be highly treatment- and cost-effective, as it applies a biopsychosocial model to account for the variety of interconnected psychological, social and biological factors contributing to pain perception in the individual.[12,14] The interdisciplinary model also combines the expertise of many healthcare professionals (e.g., physicians, psychologists, physiotherapists, occupational therapists, etc.) who communicate regularly in one facility, working towards the common goal of the patient's treatment plan and progress.[11,14] In a study by Oslund et al,[15] CP patients who completed an interdisciplinary Program reported significant reductions in pain severity, pain-related emotional distress, pain interference with daily functioning and improvements in perceived control of pain. Accordingly, many experts have deemed the interdisciplinary model superior to other methods.[11,14]

The Michael G. Degroote Pain Clinic

The Michael G. DeGroote Pain Clinic at McMaster University Medical Centre in Hamilton, Ontario is a successful interdisciplinary pain management Program that helps CP sufferers manage their pain, increase their quality of life, and regain a sense of normalcy and control. The Program's duration is four weeks, from 9:30 am to 3:30 pm, Monday to Friday. The interdisciplinary team works collaboratively to adhere to the patient's individual needs and achieve pre-established goals. Patients take part in various activities facilitated by members of the interdisciplinary team. This effectively equips patients with a diverse set of skills to help them manage their CP and increase their overall functioning. For example, patients attend fitness and nutritional classes conducted by the physiotherapist in order to learn proper ways to exercise, stretch and increase overall energy levels.

Before CP patients can attend the Program, they must be referred by a physician, specialist, lawyer, or insurance company representative, be assessed, and then recommended for admission by the interdisciplinary team. Individuals are deemed appropriate or not appropriate for the Program following the initial assessment that involves the collection of demographic information, a medical and psychological assessment, an evaluation of functional status, an assessment of the patient's engage ability and an assessment of the individual's motivation for treatment through goal setting and overall understanding of the biopsychosocial approach.

Inclusion criteria for the Program include the presence of refractory pain and/or multidimensional impairments, reasonable goals, adequate grasp of the English language, and adequate cognitive functioning (e.g., the potential patient does not have a debilitating acquired brain injury or dementia).[16] Exclusion criteria are the seeking of a cure or total analgesia, the presence of an unstable medical condition and/or substance abuse disorder, and high fall risk.[16] The interdisciplinary team is permitted to use personal discretion and clinical judgment when determining whether the individual is suitable for the Program.

Obstacles to Entering Treatment: Denial by Insurance Companies

Unfortunately, even if assessed individuals are recommended for admission into the Program by the interdisciplinary team, some may still not receive necessary treatment due to financial restrains.[17] Service and treatment costs at the Program range upwards of $11,900 and are not funded through the publicly financed Ontario Health Insurance Plan (OHIP), necessitating that patients 'pay out of pocket' or make an insurance claim. This can create an extensive financial barrier if the individual is not authorized for insurance coverage, therefore decreasing the accessibility of CP treatment.

Many patients are referred to the Program following a motor vehicle accident (MVA) and accordingly seek insurance coverage for treatment through their automobile insurance company. The Financial Services Commission of Ontario (FSCO) is a regulatory organization overseeing and legislatively mandating the province's insurance sector.[18] To address non-catastrophic injuries sustained in a MVA, the FSCO has outlined insurance

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policies for affected individuals.[19] The Minor Injury Guideline (MIGs) states that automobile insurance companies are obliged to provide funding for minor injuries at a capped $3,500.[20] Comparatively, patients with impairments falling outside of the MIGs are eligible for upwards of $50,000 in medical and rehabilitation benefits.[19] However, a MVA injury falls outside of the scope of the MIGs in extremely limited circumstances.[20] To receive funding outside of the MIGs, the injured individual must provide evidence of a pre-existing medical condition that was documented by a healthcare professional before the MVA.[20] Moreover, an individual may still be ineligible for additional funding if it is deemed that the pre-existing condition has no bearing on achieving maximum recovery from the MVA.[20] Therefore, if automobile insurance companies contend that a patient's CP from a MVA is a minor injury, they are not obligated to cover amounts exceeding the capped $3500. Approximately 20% to 50% of CP sufferers who require intervention are denied adequate financial coverage by insurance companies, therefore rendering them unable to cope effectively.[17]

Insurance providers do not explicitly disclose their reasons for denying funding to patients injured in a MVA. Therefore, it remains unknown why exactly these individuals are granted coverage for CP treatment over others.[17] To our knowledge, no study to date has investigated this line of inquiry. The present analysis will attempt to delineate any differences between those granted *versus* denied insurance coverage for CP treatment by comparing scores on pain-related and demographic information questionnaires. The research hypothesis was that the two groups would not show any significant or clinically meaningful differences. This outcome would indicate that the criteria used by insurance companies to evaluate CP treatment claims are likely systems-related (e.g., financial or administrative) rather than patient need-related, which is important to communicate to insurance companies and other stakeholders (e.g., lawyers).

METHODS

Participants and Procedures

Participants in the present study were 99 adults who attempted several pain treatments, attained little pain relief, were unsure of how to cope with their pain, and faced significant reductions in daily functioning. Participants were referred to the Program by physicians, specialists, lawyers, Veteran's Affairs, Department of Defense or insurance company representatives. Once consulted, patients attended an orientation session introducing them to the Program and were assessed by an interdisciplinary team, which evaluated the physical and psychological aspects of pain, between March 7, 2013 and November 27, 2014. Participant inclusion criteria for this study were: ≥ age of 18; self-reported CP for ≥6 months; CP due to ≥1 motor vehicle accident(s) (MVA); and recommendation for admission into the Program by the interdisciplinary team. Including patients who had CP due to ≥1 MVAs was used because CP treatment costs of this nature are limited to full or partial coverage provided by private automobile insurance companies. This criterion ensured that the type of insurance claims were consistent among participants.

Individuals were mailed demographic information and pain-related questionnaires that they were to complete and bring into their initial assessment and orientation. All study participants provided informed consent. Ethics approval was obtained by the Hamilton Integrated Research Ethics Board (HiREB) of Hamilton Health Sciences.

Measures

Data for this study were collected from the questionnaires mailed to potential Program patients before their orientation and initial assessment. Patients completed 9 questionnaires measuring pain-related variables (see below), and a demographic information questionnaire. Table 1 presents a list categorizing and defining all variables.

a) Pain Disability Index: The Pain Disability Index (PDI) assesses the extent to which CP interferes with the individual's daily functioning.[21,22] Individuals circle the number that best reflects the level of disability from 0 (no disability) to 10 (total disability) experienced for each of the 7 categories of life activities: family/home responsibilities, recreation, social activity, occupation, sexual behaviour, self care, and life support activity.[21] The final score is calculated by summing all item scores.[21] The PDI has been shown to be a reliable measure, demonstrating high internal consistency (Cronbach α=0.86)[23] and high reported test re-test reliability (Intraclass correlation (ICC=0.91)) in patients who repeated their questionnaire one week after its initial completion.[24] The construct validity of the PDI has also been established, as patients with higher PDI scores had significantly more pain characteristics including restriction of activities and psychological distress (all $p<0.001$) than patients with low PDI scores.[23] As well, the PDI has shown significant associations with other pain-related variables (e.g., depression, pain intensity, employment status).[25,26]

b) Brief Pain Inventory: On the pain intensity dimension of the Brief Pain Inventory (BPI), individuals rate their pain intensity in the previous 24 hours in terms of worst, least, average and current pain at the time of assessment on a scale of 0 (no pain) to 10 (pain as bad as you can imagine).[27] The final score is obtained by calculating the average of the summed item scores. The pain intensity scale of the BPI has been supported as a valid and reliable measure for measuring pain intensity among CP patients. It has demonstrated acceptable internal consistency with a Cronbach α coefficient of 0.85, verifying the use of the scores as outcome variables in treatment outcome analyses. The responsiveness of the BPI is also established, as the scale scores showed significant ($p<.05$) improvements in detecting and reflecting improvement in pain intensity over time, compared to other related pain scales.[27]

c) Pain Catastrophizing Scale: The Pain Catastrophizing Scale

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Variable	Description	Type of Variable
granted_denied_insurance	Whether or not the individual was granted or denied insurance coverage for chronic pain treatment at the Program	Nominal: 1=granted coverage 2=denied coverage
gender	The individual's gender	Nominal 1=male 2=female
age	The individual's age in years	Scale
yes canada_no canada	Whether or not the individual was born in Canada	Nominal: 1=born in Canada 2=not born in Canada
years in canada	The number of years the individual has lived in Canada	Scale
marital status	The marital status of the individual	Nominal: 1=married or commonlaw 2=single 3=divorced, separated, or widowed
yes children_no children	Whether or not the individual has children	Nominal 1=yes 2=no
occupation	The individual's current or last known occupation	Nominal
yes employed_no employed	Whether or not the individual is currently employed	Nominal 1=employed 2=not employed
last employed months	The number of months since the individual has worked	Scale
education years	The number of years of education attained by the individual	Scale
pain duration months	The number of months that the individual has been experiencing chronic pain	Scale
injury number	The number of injuries the individual has incurred	Scale
doctor visits	The number of times the individual has visited the doctor due to their injury or injuries and/or chronic pain	Scale
specialist visits	The number of times the individual has visited a specialist due to their injury or injuries and/or chronic pain	Scale
ER visits	The total number of times the individual has visited the emergency room due to their injury or injuries and/or chronic pain	Scale
BPI	The individual's score on the pain intensity scale of the Brief Pain Inventory prior to potential treatment (shortly before initial assessment)	Scale
CES-D	The individual's score on the Center for Epidemiologic Studies Depression Scale prior to potential treatment (shortly before initial assessment)	Scale
PCS	The individual's score on the Pain Catastrophizing Scale prior to potential treatment (shortly before initial assessment)	Scale
CAS	The individual's score on the Clinical Anxiety Scale prior to potential treatment (shortly before initial assessment)	Scale
PQ	The individual's score on the Patient Questionnaire prior to potential treatment (shortly before initial assessment)	Scale
PDI	The individual's score on the Pain Disability Index prior to potential treatment (shortly before initial assessment)	Scale
TSK	The individual's score on the Tampa Scale for Kinesiophobia prior to potential treatment (shortly before initial assessment)	Scale
CPAQae	The individual's score on the Chronic Pain Acceptance Questionnaire activity engagement subscale prior to potential treatment (shortly before initial assessment)	Scale
CPAQpw	The individual's score on the Chronic Pain Acceptance Questionnaire pain willingness subscale prior to potential treatment (shortly before initial assessment)	Scale
CPAQt	The individual's total score on the Chronic Pain Acceptance Questionnaire prior to potential treatment (shortly before initial assessment)	Scale
PSOCQpcon	The individual's score on the Pain Stages of Change Questionnaire precontemplation subscale prior to potential treatment (shortly before initial assessment)	Scale
PSOCQcont	The individual's score on the Pain Stages of Change Questionnaire contemplation subscale prior to potential treatment (shortly before initial assessment)	Scale
PSOCQacti	The individual's score on the Pain Stages of Change Questionnaire action subscale prior to potential treatment (shortly before initial assessment)	Scale
PSOCQmain	The individual's score on the Pain Stages of Change Questionnaire maintenance subscale prior to potential treatment (shortly before initial assessment)	Scale

Table 1: List of collected demographic and pain-related variables.

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(PCS) measures negative thinking about pain.[28] The PCS is composed of 14 items that are rated on a scale from 0 (not at all) to 4 (all the time).[28] The items describe various perceptions and feelings that individuals may have regarding their pain and pertain to one of three subscales: rumination, magnification, and helplessness.[28] Once the individual rates the degree to which they experience the listed thoughts and feelings, the item scores are summed and their final score is obtained.[28] The PCS has demonstrated acceptable and satisfactory internal consistency for total PCS score (α=.97) and its three subscales: rumination (α=.87), magnification (α=.60), and helplessness (α=.79).[28] Convergent validity has also been demonstrated, as evident by the moderate correlation of total PCS scores with scores on negative affectivity (r=.75, p<00.1) and self-reported anxiety measures (r=.32, p<.001).[28] Strong test-retest reliability has been established for 6 weeks (r=.75) and 10 weeks (r=.70) in a sample population.[28] Evidence for construct validity was demonstrated by confirmatory factor analysis, establishing that the scale measures a single construct (e.g. catastrophizing) described by three related dimensions (e.g., rumination, magnification, and helplessness).[29] Osman et al[29] showed that the PCS demonstrates discriminate and criterion related-validity, as none of the examined demographic variables were significantly related to PCS total or subscale scores, and total PCS scores were useful in differentiating between criterion groups (t=4.99. p=<.001), respectively.[29]

d) Patient Questionnaire of the PRIME-MD: The Patient Questionnaire of The Primary Care Evaluation of Mental Disorders (PRIME-MD PQ) functions as a preliminary symptom screen for mental disorders and measures the number of recent bothersome symptoms and overall health rating.[30] The Patient Questionnaire (PQ) instructs the individual to check off "yes" or "no" for each item in a 25-symptom list. At the end of the PQ, the individual rates their overall health as "excellent," "very good," "good," "fair," or "poor." Their final score is calculated by summing the number of times the individual checked-off "yes," on the 25 items and the rating of their overall health is noted.[30] The validity of this scale has been established by comparing independent mental health professional diagnoses against diagnoses attained by the scores of the PRIME-MD.[30] From this, the scale has demonstrated excellent overall accuracy (88%) and good agreement (κ=0.71). As well, the PQ has been shown to be a useful tool in screening mental disorders demonstrating good to excellent sensitivity across all diagnoses including mood (69%), anxiety (94%), alcohol (81%) and eating (86%) disorders.[30] Specificity measures of the PQ are comparable for mood (82%), anxiety (53%), alcohol (91%) and eating (88%) disorders.[30]

e) Pain Stages of Change Questionnaire: The Pain Stages of Change Questionnaire (PSOCQ) measures patient readiness to adopt a self-management approach to their CP condition.[31] The PSOCQ instructs the individual to rate how strongly they agree or disagree with statements using a scale from 1 (strongly disagree) to 5 (strongly agree).[32] Each item loads on to one of four stages of change: pre-contemplation, contemplation, action or maintenance.[32] A) Pre-contemplation (PSOCQpcon): Believing that the problem is mostly medical and that pain relief is left up to physicians. B) Contemplation (PSOCQcon): Willing but reluctant to adopt a self-management approach to chronic pain problems. C) Action (PSOCQacti): Reflecting on the acceptance of a self-management approach and engageability in such treatment. D) Maintenance (PSOCQmain): Reflecting on an established self-management approach and intention to continue this approach.[31] The scores for each stage are averaged, resulting in four final scores that range between 1 and 5, with scores closer to and including 5 indicating a higher probability of the individual being at a particular stage(s).[32] If the individual scores high on PSOCQcon, PSOCQacti and/or PSOCQmain, they are more likely to benefit from treatment that involves self-care strategies.[32] Data analysis supports this four-factor scale, as this model fit the data without significant deviations (X2(317)=333.68, p=>0.05) and demonstrated a goodness-of-fit index of 0.92.[31] The PSOCQ has demonstrated excellent reliability in each subscale: pre-contemplation (α=.77), contemplation (α=.82), action (α=.86), and maintenance (α=.86) and excellent test-retest reliability (α=0.74-0.88 over a one to two-week period).[31] Evidence for criterion-related validity has also been established, as measures of control, accommodation, and active coping were strongly positively related to maintenance (r=.61, r=52, r=.49 respectively) and strongly negatively related to pre-contemplation (r=−.55, r=−.37, r=−.35 respectively).[31] The PSOCQ's validity is further supported by its association with treatment outcome[31,33] its usefulness in predicting commitment in self-management pain treatment,[32] and its relationships with other pain-related measures.[34]

f) Chronic Pain Acceptance Questionnaire: The Chronic Pain Acceptance Questionnaire-Revised (CPAQ-R) measures chronic pain acceptance.[35] The CPAQ-R instructs patients to rate the degree to which each statement applies to them using a scale from 0 (never true) to 6 (always true).[35] The statements quantify one of two constructs of pain acceptance: activity engagement or pain willingness.[35] Item scores are sorted based on the acceptance construct and are subsequently added, resulting in two subscale scores and a total score (the sum of the two sub-scale scores).[35] The CPAQ-R has demonstrated good internal consistency and Cronbach alpha values for each sub-scale: activity engagement (α=0.82) and pain willingness (α=0.78), providing evidence for its reliability for its use as a pain measure.[35,36] The CPAQ-R has also demonstrated adequate predictive validity, as outcomes like depression, pain-related anxiety, and psychosocial disability could be significantly predicted by both pain willingness (all p<0.05) and activity engagement (all p<0.05) subscales.[36]

g) Tampa Scale for Kinesiophobia: The Tampa Scale for Kinesiophobia-11 (TSK-11) measures pain related fear of movement (Miller et al, Unpublished report, 1991). Individuals indicate how strongly they agree with 11 statements using from a scale of 1 (strongly disagree) to 4 (strongly agree) corresponding to one of two categories: somatic focus (tendency to notice and report physical symptoms) or activity avoidance.[37] The final

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score is obtained by summing the item scores.[37] The TSK-11's psychometric properties demonstrate good test-retest reliability (ICC=0.81, standard error of measurement (SEM)=2.54), internal consistency (α=0.79) and responsiveness (standardized response mean (SRM)=-1.11).[37,38] Additionally, The TSK-11 has established concurrent (convergent) validity and predictive validity.

h) Clinical Anxiety Scale: The Clinical Anxiety Scale (CAS) measures clinical anxiety using a scale from 1 (rarely or none of the time) to 5 (most or all of the time).[39] Individuals rate how often they have experienced each item in the 25-statement list.[39] Once the scores for items 1, 6-8, 13, 15, 16, and 17 are reversed (e.g., a score of 1 is reversed to a score of 5), the final score is calculated by summing up the individual scores and subtracting.[25,39] The CAS has been shown to be a very reliable measure indicated by a high internal consistency (α=.94) and low standard error of measurement (SEM=4.2).[40] As well, the CAS has demonstrated good known-groups discriminant validity (r=.77), effectively distinguishing between low-anxiety groups and clinical anxiety populations.[40] Moreover, it is significantly superior at discriminating these populations compared to other anxiety tools including the Rational Behaviour Inventory, Generalized Contentment Scale, and Psycho-Social Screening Package (all $p<0.002$).[40]

i) Center for Epidemiological Studies-Depressed Mood Scale: The Center for Epidemiological Studies-Depressed Mood Scale (CES-D) measures depressive symptoms in non-psychiatric samples.[41] Using a scale from 0 (rarely or none of the time; less than 1 day) to 3 (most or all of the time; 5-7 days), individuals are instructed to rate how often they have experienced each symptom in the 20-item list during the past week.[41] Most items in the list are related to depressed mood, feelings of guilt and worthlessness and helplessness. Items 4, 8, 12 and 16, however, test positive affect and are reversed before calculating the individual's final score (e.g., a score of 0 is reversed to a score of 3).[41] The final score is calculated by summing up the individual item scores.[41] While a final score of 16 indicates depressed mood in the normal population, a score of 19 suggests depressed mood in the CP population, preventing significantly higher classification of depression.[42,43] The CES-D has demonstrated high internal consistency in both the general (α=0.85) and psychiatric populations (α=0.90), and can effectively discriminate between these two groups.[41] Evaluated test-retest reliability of the CES-D has found moderate correlations (r=0.45-0.7) between initial and follow-up scores three to twelve months after the initial questionnaire was given.[41] The CES-D's criterion validity has been shown, as its scores are positively correlated with other self-report scales that measure symptoms of depression (r=0.55-0.74) and negatively correlated with scales measuring variables different from depression (r=-0.55); providing evidence for its convergent and discriminant validity, respectively.[41] The CES-D has found to be a valid measure of depressive symptoms in the general and CP populations. Moreover, it has shown good predictive validity in identifying depression in the CP population, and superior sensitivity in identifying differences in depression severity when compared to other depression scales (e.g., the Beck Depression Inventory (BDI)).[44,45]

Demographic Information

The demographics questionnaire recorded age, gender, place of birth, years living in Canada, marital status, number of children, current or last known occupation, last month/year employed, years of education, pain duration, total number of injuries, number of times individual has visited a family physician and/or specialist, and the number of times the individual has visited the emergency room.

Statistical Analysis

The scores on the above measures and questionnaires were calculated using scoring guidelines and transferred to a scoring summary sheet. All raw data, including the information obtained from the demographics questionnaire, were entered into a Microsoft Excel spreadsheet along with the participant's date of initial assessment and insurance coverage status (granted *versus* denied). Interval and ratio pain variables were analyzed in a two-way multivariate analysis of variance (two-way MANOVA). All data used in these analysis were normally distributed. The MANOVA was conducted to a) assess the main effect of the independent variables *granted_denied_insurance.* (granted *versus* denied insurance coverage for the pain treatment Program) and *gender* (male-female) on study variables (e.g., pain-related questionnaire scores) and to b) determine if there was an interaction effect between the two independent variables on the continuous study variables collectively. If interaction effects were detected, then planned follow-up analysis would be performed on any relevant covariates that should be controlled for by using a MANCOVA. Univariate between-subjects effects in the MANOVA were also analyzed for the same independent variables (e.g. *granted_denied_insurance, gender, granted_denied_insurance*gender*) against the same dependent variables (e.g. pain scores).

Each nominal demographic variable was analyzed in a Pearson chi-square test of independence, which also used *granted_denied_insurance* and gender as independent variables. Finally, each continuous demographic variable was analyzed by an independent groups t-test. All tests were performed using the statistical software package SPSS 22.0 (Statistical Package for the Social Sciences, version 22.0).

Out of the 30 variables obtained from each individual, 27 patients were missing ≥1 of these variables. In total, 91 missing values out of a possible 2970 were accounted for (>0.03%). Possible reasons for missing data include: a) failure to fully complete the demographic package (e.g., the individual left questions blank); b) the existence of a language barrier, making it difficult to complete the demographic package or one or more pain questionnaires fully; c) failure to provide a proper

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response to a numerical question (e.g., responding with "a lot" or "too many to count" when reporting number of ER visits in the demographic questionnaire). Due to these reasons, the missing data were assumed to be missing at random (MAR). In order to address these MAR data in the MANOVA analysis, a mean imputation procedure was utilized. Using the average calculated mean scores as imputed values decreases the variability among the data, yet maintains the power of the sample size.

RESULTS

Participant Demographics

In total, 99 participants were included in the analyses. There were an almost equal number of females (n=50) and males (n=49) in the sample (Table 2). The majority of the patients were born in Canada (n=67). The mean±SD age in years of the 99 participants was 46.53±11.98. Among participants who responded with a numerical value (i.e., excluding answers that were left blank or responded with 'multiple') (n=78), the average number of times the individual had visited a family physician since their pain problem began was 28.37. The majority of patients (n=59) were unemployed. The independent groups t-test yielded no significant results (p>0.05) for all continuous demographic information. Fifty individuals were deemed appropriate for treatment at the Program, granted financial coverage, and admitted into the Program. The remaining 49 individuals were also deemed appropriate, but because they were denied financial coverage, did not enter the Program.

Descriptive Statistics

Data analyzed were interval, ratio, or nominal. The interval and ratio data included 23 of the 30 collected variables. Table 3 summarizes the mean±SD clinical cut-offs and ranges of pain-related questionnaires between the group granted insurance coverage and the group denied insurance coverage. The variable *occupation* varied widely across the data set. As such, frequencies were only reported for the remaining 6 nominal variables.

Admission Scores on Pain Questionnaires

All individuals, both those granted insurance coverage (n=50) and those denied coverage (n=49), met the pre-established average ranges and clinical cut-offs for the CAS, CES-D, and PCS according to the literature.[28,40,44] Both groups' average scores were also within the average range of admission scores at the Program for the PDI, BPI, PQ, TSK, and CPAQ and PSOCQ subscales.

Patient Demographics	Granted Insurance Coverage	Denied Insurance Coverage	Independent Groups t-test on continuous variables
Age, years, mean±SD	46.56±12.02	46.49±12.06	t=0.03 , p=0.98
Sex (n): Male Female	 26 24	 24 25	N/A
Born in Canada, years: Yes No	 35 13	 32 15	N/A
Years Lived in Canada	41.09±13.65	40.61±15.62	t=0.16 , p=0.87
Marital Status (n): Married or commonlaw Single Divorced, separated, or widowed	 35 9 6	 29 10 10	N/A
Children (n): Yes No	 42 8	 34 15	N/A
Employed (n): Yes No	 18 32	 22 27	N/A
Last Employed, months, mean±SD	33.07±27.82	38.00±47.85	t=0.63, p=0.53
Education, years, mean±SD (range)	13.71±2.57	14.25±4.20	t=0.77, p=0.44
Pain Duration, months, mean±SD (range)	45.50±43.40	66.69±98.68	t=1.39, p=0.17
Number of Injuries, mean±SD (range)	1.89±1.65	1.83±1.75	t=0.18 , p=0.86
Number of Doctor Visits, mean±SD (range)	30.29±30.10	26.55±42.01	t=0.51, p=0.61
Number of Specialist Visits, mean±SD (range)	5.70±5.02	4.93±4.07	t=0.84 p=0.40
ER Visits, mean±SD (range)	1.78±4.41	1.74±2.36	t=0.06, p=0.95

Table 2: Patient demographics between those accepted *versus* denied insurance coverage.

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Pain-Related Questionnaire	Clinical Cut-Off and/ or Program Range	Mean±SD of Individuals Granted Coverage (n=50)	Mean±SD of Individuals Denied Coverage (n=49)
CAS	30 (± 5), 18-52	41.16 ±20.02	39.69±21.72
CES-D	27, 19-43	32.33±12.64	33.56±11.28
CPAQ, activities engagement	15-34	23.38±11.54	21.92±12.05
CPAQ, pain willingness	9-25	18.23±7.77	16.90±12.35
CPAQ, total	27-56	41.23±16.96	37.04±19.91
PCS	≥30, 17-42	32.08±14.05	32.83±12.28
PDI	37-57	47.73±11.70	45.08±11.57
BPI	4.5-8	6.32±1.56	6.29±1.41
PQ	9-17	13.20±2.98	13.48±3.86
PSOCQ, precontemplation	2.2-3.5	3.03±0.70	3.064±0.733
PSOCQ, contemplation	3.5-4.5	3.98±0.50	3.71±0.57
PSOCQ, action	2.8-4	3.08±0.80	3.01±0.77
PSOCQ, maintenance	2.6-3.9	3.10±0.79	3.25±0.72
TSK-11	23.63-37.09	30.42±7.11	31.85±6.51

Table 3: Clinical cut-offs and ranges of pain-related questionnaires between insurance coverage groups.

Two-Way MANOVA

A MANOVA comparing the effects of gender and insurance coverage on all continuous pain-related scales was performed. Comparing the independent variables across all pain-related measures yielded no significant main effects for *granted_denied_insurance* (F(14, 82)=1.269; *p*= 0.244; Wilks' Λ=0.822) or gender (F(14,82)=1.220; *p*=0.277; Wilks' Λ=0.828), as hypothesized. As well, there was no statistically significant interaction effect between *gender* and *granted_denied_insurance* on the dependent variables (F(14, 82)=0.632; *p*=0.830; Wilks' Λ= 0.903). Table 4 presents the results of these multivariate tests.

Univariate between-subjects effects from the MANOVA were analyzed in the context of each independent variable (e.g. *granted_denied_insurance* and *gender*) on the pain-related questionnaire scores. Those granted insurance coverage and those denied insurance coverage for the Program did not differ significantly on any pain-related measure except the *PSOCQcont* (PSOC Q contemplation score) (F(1,95)=6.161; *p*=0.015), (Cohen's d=0.5) (see Table 5). The gender groups (male or female) did not differ significantly on any pain-related measure except the *TSK*(F(1,95)=4.809; *p*=0.031) (see Table 6) and *PSOCQpcon* (PSOCQ pre-contemplation score) (F(1,95)=6.516; *p*=0.012) (see Table 7).

Effect	Wilks' Lambda Value	F	Hypothesis df	Error df	Sig.
Intercept	0.004	1344.175	14.000	82.000	.000
granted_denied_insurance	.822	1.269	14.000	82.000	.244
gender	.828	1.220	14.000	82.000	.277
granted_denied * gender	.903	.632	14.000	82.000	.803

Table 4: MANOVA results for pain questionnaire scores with *accepted_rejected* and *gender* as factors.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	2.764	3	.921	3.435	.020
Intercept	1463.162	1	1.463.162	5454.929	.000
granted_denied	1.653	1	1.653	6.161	.015*
gender	0.987	1	.987	3.679	.058
granted_denied_insurance * gender	.202	1	.202	.751	.388
Error	44.604	95	.470		
Total	1492.210	99			
Corrected Total	28.245	98			

*Significance of F value, *p*<0.05 (two-tailed).

Table 5: Between-subject results for PSOCQcon with *accepted_rejected* and *gender* as factors.

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Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	405.241	3	135.080	3.195	.027
Intercept	95568.591	1	95568.591	2260.682	.000
granted_denied_insurance	56.184	1	56.184	1.329	.252
gender	203.283	1	203.83	4.809	.031*
granted_denied_insurance * gender	150.322	1	150.322	3.556	.062
Error	4016.052	95	42.274		
Total	100368.00	99			
Corrected Total	4421.293	98			

*Significance of F value, $p<0.05$ (two-tailed).

Table 6: Between-subject results for TSK with *accepted_rejected* and *gender* as factors.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	3.138	3	1.046	2.228	.090
Intercept	914.089	1	914.089	1946.871	.000
granted_denied_insurance	.058	1	.058	.122	.727
gender	3.059	1	3.059	6.516	.012*
granted_denied_insurance * gender	.037	1	.037	.080	.778
Error	44.604	95	.470		
Total	964.120	99			
Corrected Total	47.742	98			

*Significance of F value, $p<0.05$ (two-tailed).

Table 7: Between-subjects results for PSOCQpcon with *accepted_rejected* and *gender* as factors.

Pearson Chi-Square Tests of Independence

Four (4) Pearson chi-square tests of independence were performed to determine the association between *granted_denied_insurance,* gender, and the remaining 4 nominal variables: *yescanada_nocanada, maritalstatus, yeschildren_nochildren yesemployed_noemployed*. The relationship between *granted_denied_insurance*, and each of the 4 nominal variables was non-significant (all $p>0.05$). For example *granted_denied_insurance*, *gender*, and *yescanada_nocanada* were determined to be independent of each other. Tables 8a, 8b, 8c and 8d presents Pearson Chi Square values for evaluated variables.

DISCUSSION

The present study highlights the lack of differences in demographic (e.g., age, gender, educational level, employment, marital status, etc.) and pain-related (e.g., pain-related interference, depression, anxiety, etc.) measures between groups of individuals granted *versus* denied insurance coverage. Those granted coverage were able to attend the four-week pain management Program, accessing effective treatment soon after their assessment. Those denied coverage were unable to enter the Program and receive the same potential for pain management. The above results provide evidence that individuals granted insurance coverage and individuals denied coverage for CP treatments at the Program do not differ on any clinically meaningful variables considered by the interdisciplinary team when making treatment recommendations.

Multivariate tests revealed that a) those granted *versus* denied insurance coverage did not differ significantly on collective pain-related questionnaire scores b) gender groups did not differ significantly on collective pain-related questionnaire scores and c) there was no interaction effect between insurance coverage and gender on collective pain-related questionnaire scores. This strongly implies that all patients assessed at the pain management Program and recommended for CP management were identical from a clinical standpoint, were all in need of, and should all be granted, effective interdisciplinary CP treatment.

Multiple univariate between-subjects analyses were also performed. Accordingly, due to the increased number of comparisons, Bonferoni corrections were applied to increase sensitivity and precision, and reduce the possibility of type I error.[46] By using the adjusted alpha level of 0.002 rather than 0.05, the majority of the above results would remain non-significant. As well, the significant finding of difference between insurance coverage on the PSOCQ contemplation scores ($p=0.015$), and between the genders on the TSK ($p=0.031$) and PSOCQ precontemplation scores ($p=0.012$) would now be rendered non-significant, as the p-values are greater than the adjusted alpha level of 0.002. This provides convincing evidence for the hypotheses that individuals granted insurance coverage *versus* denied coverage do not differ clinically on any pain-related or variable, as hypothesized.

Though the PSOCQcont scores in the univariate analysis significantly differ between individuals granted *versus* de-

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Gender		Value	df	Asymp. Sig (2-sided)
Male	Pearson Chi- Square	.012	1	.913
Female	Pearson Chi- Square	.783	1	.575
Total	Pearson Chi- Square	.267	1	.606

a) *yescanada_nocanada* and *granted_denied_insurance* and *gender.*

Gender		Value	df	Asymp. Sig (2-sided)
Male	Pearson Chi- Square	.242	1	.623
Female	Pearson Chi- Square	3.657	1	.056
Total	Pearson Chi- Square	2.933	1	.138

b) *yeschildren_nochildren and granted_denied_insurance and gender.*

Gender		Value	df	Asymp. Sig (2-sided)
Male	Pearson Chi- Square	.252	1	.616
Female	Pearson Chi- Square	.525	1	.469
Total	Pearson Chi- Square	.814	1	.367

c) *yesemployed_noemployed* and *granted_denied insurance* and *gender.*

Gender		Value	df	Asymp. Sig (2-sided)
Male	Pearson Chi- Square	2.090	2	.352
Female	Pearson Chi- Square	.471	2	.790
Total	Pearson Chi- Square	1.605	2	.448

d) *maritalstatus* and *granted_denied_insurance* and *gender.*

Table 8: Pearson Chi Square results for the following variables.

nied insurance coverage at the commonly accepted $p<.005$, it is important to note that the average PSOCQcont scores between individuals granted insurance coverage and those denied coverage only different by 0.26 (6.8%). In a study by Dysvik et al,[47] a 10% mean change on the PSCOQ from pre-treatment to post-treatment for CP was considered the smallest clinically important difference. Therefore, using a cut-off of 10%, the obtained mean difference of 6.8% is not clinically significant and, said alternatively, could not produce a behavioral difference between these subsets of individuals large enough to be detected by clinicians, let alone by insurance company representatives. Taking this, and the adjusted non-significant finding into account, exemplifies that individuals granted insurance coverage and those denied coverage would be equally ready to adopt a self-management approach to CP.

Clinical significance can also be determined by calculating Cohen's d, a measure of effect size.[46,48] Effect size is a statistic that gives a meaningful indication of how large the difference is between two statistically different means.[46] Using the average PSOCQ contemplation subscale scores and standard deviations for individuals granted insurance coverage and those denied coverage, a Cohen's d value of 0.5 was obtained. This indicates a medium effect size statistically.[46,48,49] However, as previously mentioned, this is not clinically important and the POSCQcont scores for both groups were in the average range for the program.

These clinically non-significant findings are contrary to the existing literature suggesting that individuals granted insurance coverage are more motivated to help themselves get better than those denied it, which might have swayed insurance company decisions to grant them coverage.[17] Given that the groups do not differ on any variables including those that are motivation-related, it would be plausible to suggest that insurance companies likely evaluate CP treatment claims using systems-related criteria (e.g., administrative or financial) *versus* patient need-related criteria.

Although not a main focus of this study, 2 other univariate analysis yielded significant results for the main effect of *gender*. Males scored significantly higher ($p<0.05$) than females on the PSOCQpcon subscale and the TSK with medium (d=.53) and small to medium (d=0.44) effect sizes, respectively. Both findings are consistent with the majority of existing literature that has examined gender differences in the PSOCQpcon subscale or TSK scores.[31,50-53] Moreover, the significant gender differences found on the PSOCQpcon and TSK further suggest that males may hold stronger beliefs that pain is a medical problem and exhibit more pain-related fear of movement correspondingly, compared to females.[31,54] However, when Bonferoni corrections were applied, the gender differences on the PSOCQ pre-contemplation subscale and TSK were no longer significant. Therefore, these differences may not be statistically or clinically significant and, consequently, may not be applied to clinical situ-

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ations (i.e., be used to tailor CP treatment according to gender).

Even in the developed nation of Canada, CP is undertreated.[55] This can be attributed to the large treatment disparity that exists between groups that can financially afford timely access to effective care, and those that cannot. A study by Peng et al[56] found that publicly funded clinics across Canada had treatment wait-times upwards of 1 year at 30% of clinics, with a range up to 5 years. These unreasonably high wait-times can have destructive results. For example, a recent systematic review by Lynch et al[55] found that patients experience significant worsening in health-related quality of life measures and psychological well-being when waiting for CP treatment for ≥6 months. Therefore, it may be in the patients' best health interest to seek timely and effective care that is provided by privately financed pain clinics.

When insurance companies receive CP treatment plan proposals from the Program, they first determine whether or not claimants will exceed their entitled $50,000 in medical and rehabilitation benefits if they were to enter the Program. Often, potential patients seeking CP relief have used the majority of their entitled funds for various medical and rehabilitation services not covered by Ontario Health Insurance Plan (OHIP) (e.g., various medical assessments and evaluations, physiotherapy, massage therapy, acupuncture, etc.) before considering an interdisciplinary Program. Consequently, these individuals would not have sufficient funds remaining to cover the approximate $11,900 in treatment costs. Unfortunately, these individuals cannot enter treatment, despite being equal in demographic and pain-related characteristics as those granted insurance coverage.

It is important to remember that all participants showed levels of anxiety, depression, catastrophizing and pain-related interference, recent bothersome symptoms, pain-related fear of movement, pain acceptance, and pain stages of change that would cause difficulties with functioning and therefore warrant clinical attention. Thus, the separation of the groups made by the insurance companies was truly artificial from a clinical perspective and not based on any tangible clinical or demographic reasons. This is important to communicate to insurance companies and other stakeholders (e.g., lawyers and other patient advocates), as it implies that individuals recommended for CP treatment require it to the same extent by clinical standards. It also stresses that those recommended be granted sufficient financial coverage to learn CP management techniques.

CONCLUSIONS

At the Michael G. DeGroote Pain Clinic of Hamilton Health Sciences, many individuals with chronic pain are denied insurance coverage for the interdisciplinary pain management Program for unspecified reasons. This study attempted to delineate the similarities and/or differences between individuals granted *versus* denied insurance using MANOVA and Pearson chi-square tests of independence. Results showed that the groups did not differ statistically or clinically, suggesting that a) the division of groups established by insurance companies was artificial from a clinical perspective; and b) insurance companies likely evaluate treatment claims using systems-related rather than patient need-related criteria, which is important to communicate to insurance companies and other stakeholders.

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CONFLICTS OF INTEREST

The authors declare that there is no conflicts of interest regarding the information discussed in this manuscript.

DISCLAIMER

The information presented reflect the views of the authors and not of McMaster University or Hamilton Health Sciences.

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Research

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Intertarget Distractors and Input Filter Compatibility in the Attentional Blink

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ABSTRACT

The Attentional Blink (AB) refers to the impairment in report accuracy of a second target when presented shortly after a first target in a stream of distractors. The main goal of the present study was to understand the nature of intertarget distractor interference in the AB by manipulating the compatibility of the distractor immediately trailing the first target and the attentional filter set to select targets preferentially for conscious report. Results show that distractor/filter compatibility had no impact on the AB, except when the distractor was of the same response category as the targets. In these conditions, the AB was larger in compatible than incompatible conditions, an effect that could be explained by an increase in misselection errors. Results are discussed in relation to extant theories of the AB.

KEYWORDS: Attentional blink; Attentional filter; Attentional selection; Distractor interference; Misselection errors.

ABBREVIATIONS: AB: Attentional Blink; RSVP: Rapid Serial Visual Presentation; TLC: Temporary Loss of Control; T1: First target; T2: Second target; ISI: Inter-stimulus interval; ANOVA: Analysis of variance.

INTRODUCTION

It is difficult to perform multiple cognitive demanding tasks concurrently, and multitasking could have a negative impact on memory and lead to negative outcomes in many fields, such as education, clinical care and in extreme work environments of the likes of air traffic control and crisis management. In the laboratory, the attentional blink (AB) paradigm[1] has been widely used to understand multitasking limitations.[2,3] In this dual-task paradigm, accurate report of a second target (T2) declines when presented within about half a second of a first target (T1) embedded in a rapid serial visual presentation (RSVP) of distractors. One important ongoing debate is whether the decline in T2 accuracy results from capacity-limitations in the consolidation of items into working memory, as postulated by capacity-based models,[4-7] or rather from failures in attentional selection of items to be consolidated, as assumed by distractor-based models.

Whereas capacity-based models assume that the AB is caused by T1 processing, distractor-based models, such as Temporary Loss of Control (TLC),[8-10] state that the AB is caused by interference of distractors during T1 processing. If a distractor is presented during consolidation of T1, it will disrupt the attentional filter set at the beginning of the trial to select targets and reject distractors optimally, leading to failures in temporal selection, which in turn can induce an increase in misselection errors.[11-17]

Contrary to TLC's main claim, it has been shown that disruption of the attentional filter is not necessary to induce an AB, given that an AB can be observed in absence of intertarget distractors.[18,19] However, intertarget distractors can directly modulate the AB without affecting T1 processing when no task switch is required between targets.[20,21] This last result cannot be

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readily explained by capacity-based accounts, suggesting that the AB is not a unitary phenomenon,[2] and that disruption of the attentional filter may play a role in modulating the AB in specific circumstances.

According to TLC, targets do not disrupt the attentional filter because they are compatible with the filter's settings. This logic implies that distractors that are compatible with the filter's settings should not disrupt the filter either, and consequently should not modulate the AB. The purpose of this study was two-folded. The first goal was to test this last assumption by manipulating distractor/filter compatibility as follows. Participants were required to identify two red uppercase letters embedded in a RSVP stream of distractors. In one block of trials, the distractor stream was composed of red digits. Given that the targets differed from the distractors only in respect to their category (letter targets and digit distractors), it was assumed that in this condition, a "category" filter would be established to select letters for – and/or reject digits from – entry into working memory. In the other block of trials, the distractor stream was composed of black letters. In this condition, distractors differed from the targets only in respect to their color (red targets and black distractors), and it was presumed that a "color" filter would be established to select red items – and/or reject black items. In other words, although the targets were defined by a conjunction of features (red and letter), only one of the two features was distinct from the distractor stream (either color in the black letter stream, or category in the red digit stream). Therefore, there is only one feature that can be used to select the targets. We hypothesized that the input filter would be configured in consequence (e.g., to let the red items through in the black letter stream or the letters through in the red digit streams).

In both blocks of trials, the distractor immediatly trailing T1 (the T1+1 distractor) could be a black digit, a black letter or a red digit. The black digit, which acts as a control, would be incompatible with the filter's settings in both blocks of trials, because it differed from the targets in both category and color. The black letter would be compatible with the "category" filter established in the red digit stream block and incompatible with the "color" filter established in the black letter stream block. Inversely, the red digit would be compatible with the "color" filter established in the black letter stream block and incompatible with the "category" filter established in the red distractor stream condition. TLC would assume that incompatible T1+1 distractors would disrupt the filter, but not compatible T1+1 distractors.

If compatible distractors do not disrupt the filter, T2 accuracy would be lowest at Lag 3 (Lag refers to the number of items following T1), because it would be the T1+2 distractor that would disrupt the filter in these conditions instead of the T1+1 distractor. Furthermore, T2 accuracy should increase from Lags 3 to 9 in compatible conditions, and should be equivalent at Lag 9 and Lag 2, indicating an absence of AB at this shortest Lag, a phenomenon that will be termed Lag-2 sparing, based on terminology used in previous studies[22] to provide a link with Lag-1 sparing, which refers to the well-known absence of a T2 deficit when no task or spatial shift occurs between targets appearing within about 150 msec from each other.[23]

The second goal was to determine whether the T1+1 distractor was mistaken for targets more often when it was compatible with the filter's setting than when it was incompatible. If this were the case, it would provide novel insights as to the role of the input filter in misselection during the AB.[11-17] To anticipate results, we observed that misselection of the T1+1 distractor was strongly modulated when it could be mistaken as a target (when T1+1 was of the same response category as the targets) and was compatible with the input filter's settings. A follow-up experiment was therefore conducted to test whether this increase in T1+1 misselection errors was caused by the compatibility of the T1+1 distractor with the input filter's setting or by a confounding factor, namely the novelty/salience of the T1+1 distractor in the compatible condition. In this follow-up experiment, novelty/salience was manipulated in conditions where the T1+1 distractor was always incompatible with the filter's settings and was always of the same response category as the targets. This was accomplished by presenting red target letters and a black or blue T1+1 distractor letter within a distractor stream that was composed of either black or blue letters.

METHODS

Participants

Sixteen undergraduate students at the *Université du Québec à Trois-Rivières* participated in each experiment for financial compensation. All reported normal or corrected-to normal vision and were naive to the purpose of the experiment. The appropriate ethics committee at the *Université du Québec à Trois-Rivières* vetted the study protocol.

Apparatus and Stimuli

The experiments were programmed in E-Prime 2.0 and were run on a Pentium PC computer, with a 16-in CRT monitor with a refresh rate of 60 Hz. The RSVP stream, presented in the center of the screen, consisted of items presented in 20-point bold Courier New font, on a white background. Targets were red uppercase letters chosen randomly from the English alphabet with the exception of B, I, O, Q, Y, and Z, with the constraint that the identities of both targets were different. There were two distractor stream conditions in the main experiment (Experiment 1A). In the red digit distractor stream condition, the distractor stream consisted of red digits selected randomly, with replacement, from the set of digits 2-9, with the constraint that the selected digit was not one of the two preceding items. In the black letter distractor stream condition, a subset of eight uppercase letters were chosen before each trial from the English alphabet with the exception of B, I, O, Q, Y, Z, the letters chosen as T1, as T1+1 (when T1+1 was a letter) and as T2. Letters from this subset were selected randomly, with replacement, with the constraint

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that the selected letter was not one of the two preceding items. In both distractor stream conditions, the distractors immediately trailing T1 (T1+1 distractor) could be a black digit, a black letter, or a red digit. The identity of the T1+1 distractor was never the same as the identity of either targets, nor as the identity of the other distractors in the stream.

Each item in the RSVP stream remained on the screen for 100 msec, and was immediately followed by the next item without any inter-stimulus interval (ISI), yielding a presentation rate of 10 items/sec. The number of distractors preceding T1 was determined randomly on each trial and varied between 6 and 12. T2 was presented either at Lag 2, at Lag 3, at Lag 4 or at Lag 9, and was followed by only one distractor that acted as a mask.

In the follow-up experiment (Experiment 1B), the stimuli were identical, with the exception that the distractor streams were composed of either blue uppercase letters or black uppercase letters and the T1+1 distractor was either a blue letter or a black letter. (Figure 1)

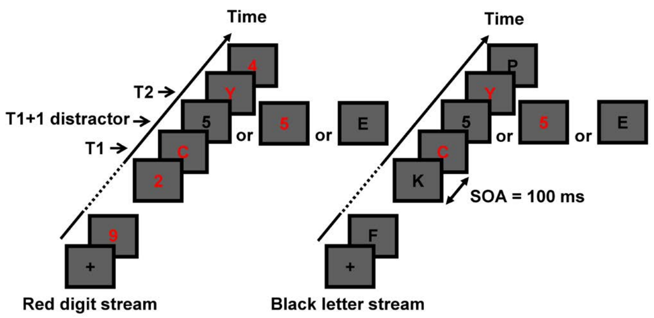

Figure 1: Illustration of the RSVP streams used in Experiment 1A for both distractor stream conditions at the T1-T2 Lag 2. Two separate unspeeded responses were required on each trial.

Design and Procedure

Each participant took part in one experimental session. Experiment 1A consisted of two experimental blocks of 240 trials, each preceded by one practice block of 12 trials. Distractor stream conditions were blocked (order counterbalanced between subjects). T1+1 distractor and T1-T2 Lag conditions were randomly intermixed in each block of trials. Experiment 1B consisted of two experimental blocks of 160 trials, each preceded by one practice block of 8 trials. Distractor stream conditions were blocked (order counterbalanced between subjects). T1+1 distractor and T1-T2 Lag conditions were randomly intermixed in each block of trials.

For both experiments, participants were required to read the instructions displayed on the screen at the beginning of the session, and were invited to ask questions to clarify procedural points if needed. Participants were required to report, without speed pressure, the identity of the red letters (T1 and T2), by pressing the corresponding key on the keyboard when prompted.

Each trial began with a small black fixation cross presented in the center of the screen, indicating the location at which the RSVP stream was about to appear. Participants initiated each trial by pressing the space bar. The RSVP stream started 200-500 msec after trial initiation. Two hundred to five hundred msec after the stream ended, a first question, "*Quelle était la première lettre rouge* [French, meaning: What was the first red letter?]", was displayed until response. A second question, "*Quelle était la seconde lettre rouge* [French, meaning: What was the second red letter?]", was displayed immediately after the first response, until the second response was executed, at which point the fixation cross reappeared, indicating that the participant could initiate the next trial when desired.

RESULTS

The instructions in both experiments explicitly informed participants to respond to targets in order of appearance. Consequently, temporal order of report of targets was taken into account when scoring the accuracy of the responses (i.e., T1 was scored as correct only if it was reported as T1, and T2 was scored as correct only if it was reported as T2). A Greenhouse-Geisser procedure was applied when appropriate to counter violations of the sphericity assumption.

Experiment 1A

T1 performance: Mean accuracy for T1 is plotted as a function of T1+1 distractor and T1-T2 Lag in Figure 2 for the red digit distractor stream (upper left panel) and for the black letter distractor stream conditions (upper right panel). Mean accuracy of T1 was submitted to a repeated measures analysis of variance (ANOVA) in which distractor stream, (2 levels: red digit stream and black letter stream), T1+1 distractor (3 levels: compatible, incompatible, control), and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9), were included as within-subject factors.[Footnote1]

The distractor stream × T1+1 distractor × Lag interaction was not significant, $F(6, 90)=1.86$; $\eta_p^2=.110$; $p>.05$, nor was the T1+1 distractor × Lag interaction, $F<1$. However, a distractor stream × Lag interaction was observed, $F(3, 45)=3.41$; $\eta_p^2=.185$; $p<.05$, as well as a distractor stream × T1+1 distractor interaction, $F(2, 28)=63.12$; $\eta_p^2=.808$, $p<.05$. To understand these significant interactions, subsequent analyses were performed for each distractor stream condition.

In the red digit stream condition, a main effect of Lag was present, $F(3, 45)=7.55$; $\eta_p^2=.335$; $p<.05$, with T1 accuracy increasing progressively with Lag. The main effect of T1+1 distractor was also significant, $F(2, 30)=78.02$; $\eta_p^2=.839$; $p<.05$. The T1+1 condition × Lag interaction, on the other hand, was

[1]A preliminary analysis including block order as a between-subject factor in mixed ANOVAs were performed for both T1 and T2 performance. No main effect or interactions with this factor were significant when analyzing T1 performance. No main effect or interactions with this factor were significant when analyzing T2 performance, except for the block order × distractor stream interaction, $F(1, 14)=8.85$; $\eta_p^2=.387$; $p<.05$, which revealed practice effects. Block order was therefore excluded from further analysis.

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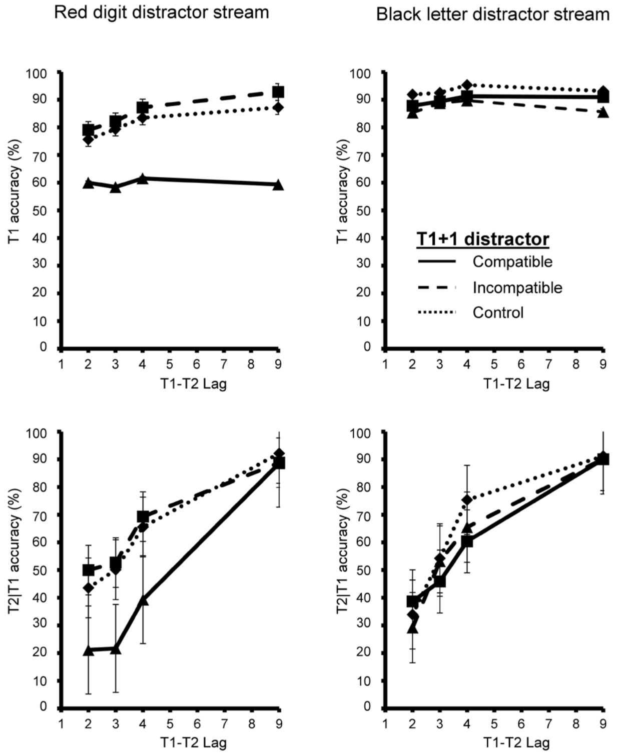

Figure 2: Results from Experiment 1A. Mean accuracy for T1 (first target) is plotted as a function of T1+1 distractor and T1-T2 Lag for the red digit distractor stream condition in the upper left panel and for the black letter distractor stream condition in the upper right panel. Mean accuracy for T2 (second target) in trials where T1 was correctly reported (T2|T1) is plotted as a function of T1+1 distractor and T1-T2 Lag for the red digit distractor stream condition in the lower left panel and for the black letter distractor stream condition in the lower right panel. Error bars represent standard error of the mean.

not significant $F(6, 90)=1.87$; $\eta_p^2=.111$; $p>.05$. Scheffé's contrast procedure[24,25] showed that T1 accuracy was lower in the compatible condition (mean T1 accuracy=60%) than in the incompatible (mean T1 accuracy=85%) and in the control conditions (mean T1 accuracy=81%, $F_{Scheffé}(2, 30)=149.80$; $p<.10$).[Footnote2] No significant difference was observed between the two latter conditions, $F_{Scheffé}(2, 30)=3.09$; $p>.10$.

In the black letter stream condition, the main effect of Lag was not significant, $F(3, 45)=1.87$; $\eta_p^2=.111$; $p>.05$, nor was the T1+1 condition × Lag interaction, $F<1$. However, a main effect of T1+1 distractor was observed, $F(2, 30)=10.44$; $\eta_p^2=.410$; $p<.05$. Scheffé's contrast procedure showed that T1 accuracy was slightly higher in the control condition (mean T1 accuracy=93%) than in the compatible (mean T1 accuracy=90%, $F_{Scheffé}(2, 30)=6.74$; $p<.10$) and in the incompatible condition (mean T1 accuracy=87%, $F_{Scheffé}(2, 30)=20.50$; $p<.10$) . No significant difference was observed between the two latter conditions, $F_{Scheffé}(2, 30)=3.73$; $p>.10$.

T1 misselection errors: To measure T1 misselection errors, we first selected the trials in which T1 was incorrectly reported, using only trials where the T1+1 distractor was a black letter (which are the only trials in which the T1+1 distractor was of the same response category as the targets). We then calculated the percentage of these trials where the T1+1 distractor was mistaken for T1 (Figure 3, left panel). Finally, the data were submitted to a repeated measures ANOVA with T1+1 compatibility (2 levels: compatible and incompatible) and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9), as within-subject factors. Six participants were excluded from the analysis because they had no T1 incorrect trials in at least one T1+1 distractor × Lag cell. A main effect of T1+1 compatibility was observed, $F(1, 9)=8.79$; $\eta_p^2=.494$; $p<.05$, indicating that participants mistook the T1+1 distractor for T1 more often in the compatible condition (63%) than the incompatible condition (47%). The main effect of Lag was not significant, $F(3, 27)=1.92$; $\eta_p^2=.176$; $p>.05$, nor was the interaction between the two factors, $F<1$.

T2|T1 performance: Mean accuracy for T2|T1 is plotted as a function of T1+1 distractor and T1-T2 Lag in Figure 2 for the red digit distractor stream (lower left panel) and for the black letter distractor stream conditions (lower right panel). Mean accuracy of T2|T1 was also submitted to a 2×3×4 repeated measures ANOVA with distractor stream, T1+1 distractor and T1-T2 Lag as within-subject factors.

A triple interaction was observed, $F(6, 90)=5.04$; $\eta_p^2=.251$; $p<.05$. To understand this interaction, subsequent analyses were performed for each distractor stream condition. In the red digit stream condition, the main effect of Lag was significant, $F(3, 45)=61.40$; $\eta_p^2=.804$; $p<.05$, showing that T2

[2]As proposed by Scheffé, this test was run at α=.10, to overcome its low power.[26]

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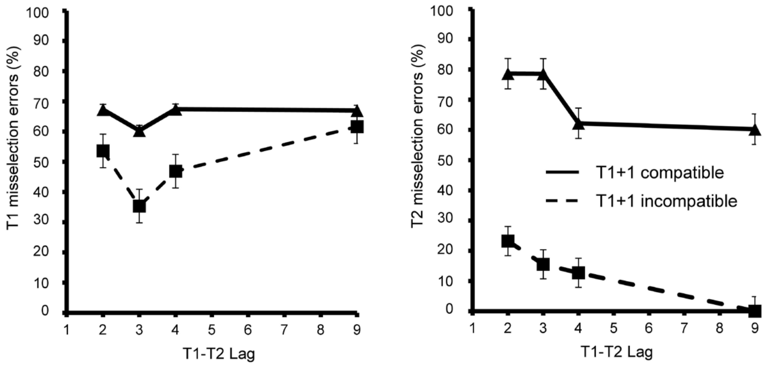

Figure 3: Results from Experiment 1A. Percentage of T1 misselection errors in incorrectly reported T1 (left panel) and percentage of T2 misselection errors in correctly reported T1 and incorrectly reported T2 trials (right panel) when the T1+1 distractor was a black letter, plotted as a function of T1-T2 Lag and T1+1 compatibility conditions. Error bars represent standard error of the mean.

accuracy increased from Lag 2 to Lag 9, which indicates that an AB was observed. The main effect of T1+1 distractor was also significant, $F(2, 30)=43.76$; $\eta_p^2=.745$; $p<.05$. Scheffé's contrast procedure showed that T2 accuracy was lower in the compatible condition (mean T2 accuracy=43%) than in the incompatible (mean T2 accuracy=65%) and in the control condition (mean T2 accuracy=63%; $F_{Scheffé}(2, 30)=77.68$; $p<.10$). No significant difference was observed between the two latter conditions, $F_{Scheffé}<1$. The T1+1 distractor × Lag interaction was also significant, $F(6, 90)=7.66$; $\eta_p^2=.338$; $p<.05$. Scheffé's contrast procedure indicated that the AB (calculated as Lag 9 minus Lag 2) was larger in the compatible condition (mean AB: 68%) compared to the incompatible condition (mean AB: 39%), and the control condition (mean AB: 49%), $F_{Scheffé}(2, 30)=28.96$; $p<.10$. No significant difference was observed between the two latter conditions, $F_{Scheffé}(2, 30)=3.69$; $p>.10$.

In the black letter stream condition, the main effect of Lag was still significant, $F(3, 45)=57.40$; $\eta_p^2=.793$; $p<.05$. However, the main effect of T1+1 distractor was not, $F(2, 30)=2.40$; $\eta_p^2=.138$; $p>.05$. Although a T1+1 distractor × Lag interaction was observed, $F(6, 90)=3.53$; $\eta_p^2=.190$; $p<.05$, Scheffé's contrast procedure revealed only a marginally significant attenuation of the AB in the compatible condition (mean AB: 51%) compared to the control condition (mean AB: 57%) and the incompatible condition (mean AB:61%), $F_{Scheffé}(2, 30)=3.89$; $p>.10$, and no significant difference between the two latter conditions, $F_{Scheffé}<1$.

To investigate whether the T1+1 distractor × Lag interactions observed above were the consequence of the compatibility of the T1+1 distractor with the input filter, or the result of distractors category (digit or letter), we performed a repeated measures ANOVA for each T1+1 category (digit and letter), with T1+1 compatibility (2 levels: compatible and incompatible) and Lag (4 levels: Lag 2, Lag 3, Lag 4, and Lag 5) as within subject factors. If compatibility of the T1+1 distractor with the input filter drove the above interactions, then we should observe a T1+1 compatibility × Lag interaction for both T1+1 categories.

When the T1+1 distractor was a letter, a T1 compatibility × Lag interaction was observed, $F(3, 45)=7.90$; $\eta_p^2=.345$; $p<.05$, as well as a main effect of T1 compatibility, $F(1, 15)=14.07$; $\eta_p^2=.484$; $p<.05$. However, when the T1+1 distractor was a digit, the T1 compatibility × Lag interaction was not significant, $F(3, 45)=1.64$; $\eta_p^2=.099$; $p>.05$, nor was the main effect of T1 compatibility effect, $F(1,15)=3.30$; $\eta_p^2=.180$; $p>.05$.

T2 misselection errors: To measure T2 misselection errors in T1 correct trials, we first selected the trials in which T1 was correctly reported but T2 was not correctly reported, using only trials where the T1+1 distractor was a black letter. We then calculated the percentage of these trials where the T1+1 distractor was mistaken for T2 (Figure 3, right panel). Finally, the data were submitted to a repeated measures ANOVA with T1+1 compatibility (2 levels: compatible and incompatible) and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9), as within-subject factors. Eight participants were excluded from the analysis because they had no T2 incorrect trials in at least one T1+1 distractor × Lag cell. A main effect of T1+1 compatibility was observed, $F(1, 7)=71.49$; $\eta_p^2=.911$; $p<.05$, indicating that participants mistook the T1+1 distractor for T2 more often in the compatible condition (70%) than the incompatible condition (14%). The main effect of Lag was not significant, $F(3, 21)=2.10$; $\eta_p^2=.231$; $p>.05$, nor was the interaction between the two factors, $F<1$.

Experiment 1B

T1 performance: Mean accuracy for T1 is plotted as a function of T1+1 distractor and T1-T2 Lag in Figure 4 for the blue letter distractor stream (upper left panel) and for the black letter distractor stream conditions (upper right panel). Mean accuracy of T1 was submitted to an ANOVA in which distractors stream (2 levels: blue letter stream and black letter stream), T1+1 distractor (2 levels: same color and different color), and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9), were included as within-subject factors. No main effects or interactions were observed (all $Fs<1.7$, except the main effect of Lag, $F(3, 45)=2.33$; $\eta_p^2=.134$; $p>.05$).

T1 misselection errors: The percentage of T1 misselection errors is plotted as a function of T1+1 distractor conditions, T1-T2 Lag and distractor stream in Figure 5 (upper panels). A repeated

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measures ANOVA was performed, with distractors stream (2 levels: blue letter stream and black letter stream), T1+1 distractor (2 levels: same color and different color), and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9) as within-subject factors. Eight participants were excluded from the analysis because they had no T1 incorrect trials in at least one T1+1 distractor × Lag cell. No main effects or interactions were observed (all *Fs*<2.03, all *ps*>.17). Note that the absence of any effects in this analysis could be the result of the large number of excluded participants combined with the low number of incorrect T1 trials in Experiment 1B.

T2|T1 performance: Mean accuracy for T2|T1 is plotted as a function of T1+1 distractor and T1-T2 Lag in Figure 4 for the blue letter distractor stream (lower left panel) and for the black letter distractor stream conditions (lower right panel). Mean accuracy of T2|T1 was also submitted to a repeated measures ANOVA with distractors stream (2 levels: blue letter stream and black letter stream), T1+1 distractor (2 levels: same color and different color), and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9) as within-subject factors. As in Experiment 1A, T2|T1 performance was lowest at the shortest Lag and increased as Lag increased, leading to a main effect of Lag, $F(3, 45)=62.64$; $\eta_p^2=.807$; $p<.05$.The main effect of distractor stream was not significant, $F(1,15)=1.52$; $\eta_p^2=.092$; $p>.05$, nor was the interaction between distractor stream and Lag, $F(3,45)=1.24$; $\eta_p^2=.076$; $p<.05$. Importantly for the purpose of Experiment 1B, the main effect of T1+1 distractor was not significant, $F(1,15)=1.52$; $\eta_p^2=.092$; $p>.05$, nor was the interaction between T1+1 distractor and distractor stream, $F<1$.

T2 misselection errors: The percentage of T2 misselection errors is plotted as a function of T1+1 distractor conditions, T1-T2 Lag and distractor stream in Figure 5 (lower panels). A repeated measures ANOVA was performed, with distractors stream (2 levels: blue letter stream and black letter stream), T1+1 distractor (2 levels: same color and different color), and T1-T2 Lag (4 levels: Lag 2, Lag 3, Lag 4, Lag 9) as within-subject factors. Ten participants were excluded from the analysis because they had no T2 incorrect trials in at least one T1+1 distractor × Lag cell. A main effect of Lag was observed, $F(3,15)=6.27$; $\eta_p^2=.556$; $p<.05$, indicating that T2 misselection occurred more often at shorter than longer T1-T2 Lags. All other main effects and interactions were not significant (all *Fs*<1), indicating that novelty had no impact on misselection of the T1+1 distractor.

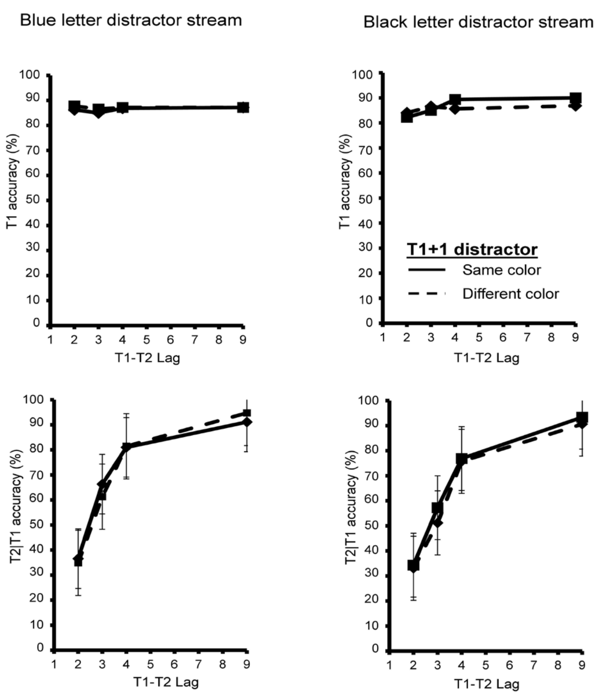

Figure 4: Results from Experiment 1B. Mean accuracy for T1 is plotted as a function of T1+1 distractor and T1-T2 Lag for the blue letter distractor stream in the upper left panel and for the black letter distractor stream conditions in the upper right panel. Mean accuracy for T2 in trials where T1 was correctly reported (T2|T1) is plotted as a function of T1+1 distractor and T1-T2 Lag for the blue letter distractor stream condition in the lower left panel and for the black letter distractor stream condition in the lower right panel. Error bars represent standard error of the mean.

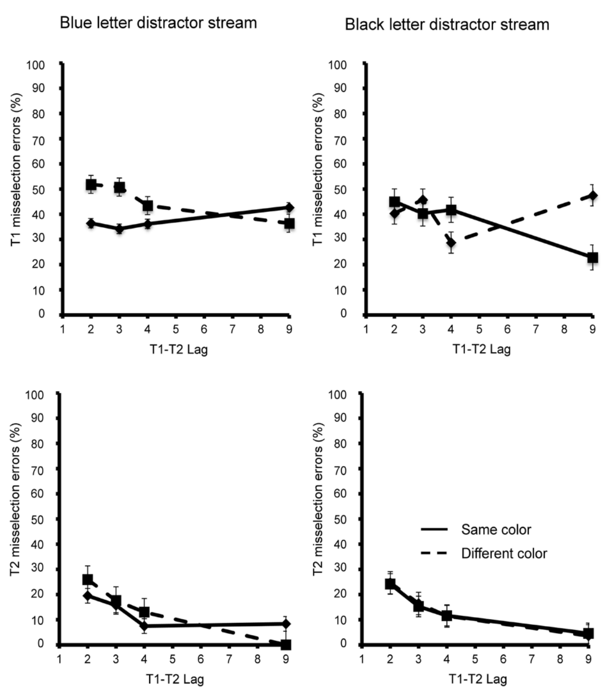

Figure 5: Results from Experiment 1B. Percentage of T1 misselection errors in incorrect T1 trials (upper panels) and of T2 misselection errors in correctly reported T1 and incorrectly reported T2 trials (lower panels), plotted as a function of T1+1 distractor and T1-T2 Lag for the blue letter distractor stream condition (left panels) and for the black letter distractor stream condition (right panels). Error bars represent standard error of the mean.

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DISCUSSION

The present study was conducted to investigate how compatibility of the distractor immediately trailing T1 (T1+1 distractor) with the attentional filter's settings affects T2 performance and misselection errors in the AB.

Investigating distractor/filter compatibility is particularly important to evaluate the Temporary Loss of Control (TLC) theory.[8-10] TLC is a distractor-based theory that assumes that distractors presented between targets (known as intervening, or intertarget distractors) are the root cause of the AB. These theories have been challenged by the observation that an AB can be observed in absence of intertarget distractors.[18,21,27] Although intertarget distractors may not be necessary to observe an AB, they can directly modulate the effect when no task switch is required between targets,[20,21] suggesting that distractor-based interference may nevertheless play an important role in the deficit.

TLC predicts that compatible T1+1 distractors should not disrupt the attentional filter's settings and consequently should spare the following item in the RSVP stream from the AB deficit. In other words, according to TLC, we should observe Lag-2 sparing in the compatible T1+1 conditions in the same manner as the third of three successive targets is spared from an AB.[8] Contrary to this prediction, we did not observe any effect of T1+1 distractor compatibility on the AB, when the T1+1 distractor was a digit.

The absence of Lag-2 sparing is in opposition to a previous study that used a similar manipulation.[15] In this study, participants had to identify two red letter targets embedded in a black digit stream of distractors. There were three main conditions: (1) a standard condition where all distractors were black, (2) a T1+1 red condition where the T1+1 distractor was red, and (3) a T1+2 red condition where the T1+1 and T1+2 red distractors were red. Although sparing was observed in the T1+1 and T1+2 red distractor conditions, this effect may have been the results of cueing, which is known to attenuate the AB.[14,28] Indeed, in the task designed by Olivers and Meeter, targets differed from distractors along two features (color and category). Given that color facilitated – but was not required for – target selection, participants could perform the task successfully, in all conditions, by using a category-filter. This is a critical difference with the current study, where targets differed from distractors in only one feature (color or category) in most conditions, forcing participants to implement either a color-filter or a category-filter.

The absence of a compatibility effect with digit T1+1 distractors was the first evidence against TLC. When the T1+1 distractor was a letter, and therefore could be mistaken as a target, a compatibility effect was observed, but in the opposite direction as TLC predicted. These results are hard to reconcile with the TLC framework. Furthermore, the last results supports an important assumption underlying our design, mainly that participants would adopt a "red" color-filter in the black letter distractor stream and a "letter" category-filter in the red digit distractor stream condition, rather than a more precise "red letter" filter in both distractor stream conditions. If participants would have adopted a "red letter" filter in all conditions, than all types of T1+1 distractors would have been incompatible with all filters, and therefore no effect of T1+1 compatibility would have been observed. Given the effect of T1+1 compatibility observed in the red digit stream condition of the main experiment (Experiment 1A), we can be rather confident that our initial assumption is valid, and that the observed results cannot be explained simply by an inefficient manipulation of T1+1 distractor compatibility. But what could explain the increase in AB amplitude in the T1+1 compatible condition when the T1+1 distractor was a letter?

Interestingly, it could be explained by an increase in misselection errors. Specifically, when the T1+1 distractor was a letter, participants tended to misselect this item as targets. T2 misselection occurred three-to-four times more often when it was compatible with the filter's settings than when it was not. Although more distractors could be mistaken for targets in the black letter stream than in the red digit stream, this could not explain the whole of the effect. Indeed, items that are misselected tend to be the items immediately preceding or trailing the targets.[17,29] Consequently, in trials where T1 was correctly identified and misselection occurred, the misselected item would be either the distractor immediately trailing or immediately leading T2, which would double the probability of misselection that was observed in the black letter stream. However, the main effect of T1+1 compatibility was still observed when doubling- and even tripling- the probability of misselection in the black letter stream.[Footnote3] Note that the increase in misselection errors also suggests that category was effectively filtered while color was mostly ignored in the red digit stream trials, increasing the probability that a black letter would be reported as a target.

T1 performance was also lowest in the compatible red digit distractor condition, which could be an indication that the T1+1 distractor in this condition increased T1 difficulty in correctly reported trials, which in turn produced a larger blink.[19,30,31] However, misselection of T1 was also greater in this condition. If we considered T1 misselection trials as correct T1 trials, no main effect of T1+1 distractor or interaction with this factor was observed. This suggests that T1 processing was not more difficult in the compatible red digit stream condition when T1 was correctly selected and reported.

It is important to notice however that in the main experiment, the T1+1 letter distractor was salient and novel in the compatible condition (the only black item in a red distractor stream), whereas it was similar to the other distractors in the incompatible condition (one of several black letters in a black letter distractor stream). The distinctiveness of the T1+1 distractor in the compatible condition could have exogenously captured attention[32,33] and hence increased its likelihood of entering work-

[3]Tripling the probability of misselection led to a compability x Lag interaction, indicating that a compatibility effect was observed at all Lags, except Lag 2.

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ing memory for further report. However, the follow-up experiment (Experiment 1B) provided evidence against this hypothesis. Indeed, results showed that novelty/salience of the T1+1 distractors does not modulate the AB nor the number of T2 or T1 misselection errors when the distractor is incompatible with the filter's settings. Some theories of attentional capture, such as the attentional control theory,[34] suggest that compatibility with the filter's settings inherently increases saliency of compatible items, leading to greater attentional capture. It may also be proposed that the novel item was not as salient here than in the former experiment, given that targets were also of a different color than the distractor stream in the present experiment, but not in the red digit stream of the main experiment. Nevertheless, the results of the follow-up experiment support the view that compatibility of the T1+1 distractor with the input filter's settings is a critical factor driving the increase in misselection errors observed in the main experiment. Again, this conclusion is consistent with the attentional capture literature, which proposes that attentional capture only occurs when the item matches the attentional control settings.[35] This conclusion is also in line with the absence of an effect in the control T1+1 distractor condition of the red distractor stream of the main experiment, where the T1+1 distractor was salient, but was not compatible with the filter's setting.

It has recently been suggested that features from consecutive items may merge in conditions leading to Lag-1 sparing.[36] It is therefore possible that the identity of the T1+1 distractor letter may have combined with the red color of T1 in some of the compatible red digit stream trials. This could explain the increase in T1 misselection errors in these trials. However, it cannot explain the large increase in T2 misselection errors at all Lags when T1 was correctly reported, since it would only predict an increase in T2 misselection errors at Lag 2, which is the only Lag where T2 immediately follows the T1+1 distractor.

The present results support the claim that misselection may play an important role in the AB.[14,17,28] However, contrary to many of the previous studies which have observed a propensity of T2+1 misselection errors in the AB,[11,16,17,29,37] here we highlight T1+1 misselection errors on both T1 and T2, and show that these types of errors are highly dependent on the relationship between the misselected item and the settings of the input filter.

Although T1+1 distractor misselection modulated the AB when the misselected item was compatible with the attentional filter's settings and was of the same response category as the target, and AB was observed in all conditions, which indicates that although misselection can modulate the AB significantly, it is not necessarily the main cause of the AB. In fact, the present results support the view that the AB is not a unitary phenomenon and that different AB tasks reflect distinct processing limitations,[20,38] which could include task-switching,[23] capacity-limitations in working memory consolidation[4,5,39] and/or distractor-based interference that impacts on target selection processes.[11,13,16,21]

In summary, the present study provides strong evidence against one key assumption of the TLC framework, which states that items that are compatible with the input filter's settings will not elicit an AB, by showing that T1+1 distractors that are compatible with the input filter's settings do not lead to Lag-2 sparing. However, we show that compatibility of the T1+1 distractor with the input filter can modulate the AB by varying T1+1 distractor misselection errors, which increases dramatically in compatible conditions.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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