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# Social reciprocity measures based on dyadic discrepancies: Methodological review and software development

David Leiva[1], Amara Andrés, and Rumen Manolov

Department of Behavioural Sciences Methods
Faculty of Psychology
University of Barcelona

**RESUMEN**

El presente artículo revisa el análisis estadístico de la reciprocidad social a nivel grupal, diádico e individual. Puesto que es también necesario el contraste de hipótesis respecto a la reciprocidad social, se ha desarrollado un procedimiento estadístico implementado en R, basado en muestreo Montecarlo, que permite a los investigadores describir y tomar decisiones respecto a un determinado grupo.

**Palabras clave**: Reciprocidad social, pruebas estadísticas, análisis de datos diádico.

**ABSTRACT**

This paper examines statistical analysis of social reciprocity at group, dyadic, and individual levels. Given that testing statistical hypotheses regarding social reciprocity can be also of interest, a statistical procedure based on Monte Carlo sampling has been developed and implemented in R in order to allow social researchers to describe groups and make statistical decisions.

**Keywords:** Social reciprocity, statistical tests, dyadic data analysis.

[1] David Leiva, Departament de Metodologia de les Ciències del Comportament, Facultat de Psicologia, Universitat de Barcelona, Passeig de la Vall d'Hebron, 171, 08035-Barcelona, Spain.
Electronic mail may be sent to David Leiva at: dleivaur@ub.edu

## 1.- Introduction

The present paper focuses on quantifying social reciprocity at descriptive and inferential levels on the basis of dyadic discrepancies. Two statistics for measuring the degree of reciprocation in social interactions are reviewed and their calculus is illustrated on psychological data. Given that there is no statistical software available to researchers in order to apply the procedures of social reciprocity based on dyadic discrepancies here reviewed, an R package has been developed incorporating the indices and statistical tests at individual, dyadic, and global levels of analysis.

Social reciprocity, defined as the exchange of similar behaviour (Hemelrijk, 1990a, 1990b; Kenny, Kashy, & Cook, 2006; Solanas, Salafranca, Riba, Sierra, & Leiva, 2006; Warner, Kenny, & Stoto, 1979), is a topic of interest when analysing social interaction in the context of areas such as social psychology, ethology, organisational psychology, family assessment, or health psychology. Although social researchers have traditionally associated reciprocity to helping behaviour (Gouldner, 1960), this social phenomenon includes a wider set of possible social behaviours and provides unique information about mutual influence in social systems. Maintaining a reciprocal interaction pattern has positive effects on individual health (Liang, Krause, & Bennet, 2001; Väänänen, Buunk, Kivimäki, Pentti, & Vahtera, 2005), on organisational functioning (Dabos & Rousseau, 2004; Wayne, Shore, Bommer, & Tetrick, 2002), and on family dynamics (Cook, 1994; Howe & Recchia, 2005). The study of reciprocity, as any social issue, requires dealing with several levels of analysis. These levels involve focusing on individuals, on pairs of individuals (dyads), or on groups (Kenny & Judd, 1986; Kenny & La Voie, 1984; Malloy & Albright, 2001; Wasserman & Faust, 1994). Research on social reciprocity implies studying the social influence between individuals. Many social researchers have focused on mutual influence between pairs of individuals (i.e., dyads) in order to explain social interaction (Cook 2005; Cook & Kenny, 2004; Howe & Recchia, 2005; Kenny, Albright, & Malloy, 1988). Apart from dyads, other possible units of analysis are triads or other larger subgroups (Lashley & Bond, 1997; Wasserman & Faust, 1994).

Several designs have been proposed to analyse dyadic data (Kenny et al., 2006). The present paper centres on round-robin designs, which require all individuals to be able to interact with their partners in the group (Gill & Swartz, 2001; Kenny, Mohr, & Levesque, 2001). One way of representing social interaction data in a round-robin design is by means of sociomatrices in which each element $x_{ij}$ of that matrix denotes the amount of behaviour (e.g., frequency, duration) that individual $i$ addresses to individual $j$. Self-addressed behaviour is not commonly studied in round-robin research and, therefore, all the $x_{ii}$ elements in the matrix are often equal to $0$. When the research interest is in measuring links among individuals, binary sociomatrices should be used (Wasserman & Faust, 1994).

The first section of the current review presents several indices for quantifying social reciprocity in round-robin designs. The second section focuses on the statistical test associated with these measures, explaining the Monte Carlo procedure on which it is based. The third section explains the functioning of the R package that includes these measures and tests. In the final section, the techniques are illustrated by an example taken from an empirical behavioural research.

## 2.- Quantifying social reciprocity at different levels of analysis

Several procedures have been developed in order to quantify social reciprocity in groups (Hemelrijk 1990a, 1990b; Solanas et al., 2006; Warner et al., 1979). Two main approaches can be followed when measuring social reciprocity: a) correlational procedures such as Mantel's (1967) Z statistic and the reciprocity indices proposed within the Social Relations Model (SRM; Kenny & La Voie, 1984; Kenny & Nasby, 1980; Lashley & Bond, 1997; Warner et al., 1979) measure association between the amounts of behaviour addressed and received in dyadic interactions and, thus, offer a quantification of reciprocity only at the global level; b) the dyadic discrepancies approach is based on differences between addressing and receiving any social behaviour within dyads and is represented by procedures like the directional consistency (DC; van Hooff & Wensing, 1987) and the skew-symmetry ($\Phi$; Solanas et al., 2006) indices which are the focus of the present paper. Both indices can be positioned in the actor-receiver model as they assume that actors in dyads compare what is given and received from their partners, without taking into account what is given and received from the others. The actor-receiver model is a parsimonious approach to study social reciprocity, since it does not require individuals to have complex cognitive abilities such as the ones assumed by the actor-reactor model (Hemelrijk, 1990a). Three types of reciprocity can be studied by means of the actor-receiver model: absolute, relative, and qualitative. A group shows absolute reciprocity when there is exact matching between the amounts of behaviour individuals interchange. Relative reciprocity requires data to be ranked within each individual, while qualitative reciprocity means that comparisons are made on a binary scale (for more details see Hemelrijk, 1990a). Both the DC and the $\Phi$ indices focus on absolute reciprocity, since that they measure symmetry of a sociomatrix, defined as the balance in the number of behaviours given and received among individuals within dyads.

The DC index was developed in order to quantify the directionality of behaviour in social interactions and has been widely used by biologists (e.g., Côté, 2000; Pelletier & Festa-Bianchet, 2006; Stevens, Vervaecke, de Vries, & van Elsacker, 2005; Vogel, 2005). The DC index is obtained by dividing the difference between the number of interactions in the most frequent (H) and in the less frequent direction (L) by the total of interactions performed by all the individuals in the group (H+L). The index can be computed from sociomatrices through the sum of absolute dyadic discrepancies divided by the total number of interactions in the group:

$$DC = \sum_{i=1}^{n} \sum_{\substack{j=i+1 \\ j \neq i}}^{n} \left| x_{ij} - x_{ji} \right| \Big/ N \, ; \quad N = \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} x_{ij} ; \quad 0 \leq DC \leq 1 \, ,$$

where $x_{ij}$ is the amount of behaviour that individual $i$ addresses to the individual $j$, $x_{ji}$ is the number of behaviours that agent $i$ receives from agent $j$, $N$ is the total number of interactions in the group, and $n$ is the number of individuals. The index ranges from *0*, maximum social reciprocity, to *1*, indicating unidirectional dyadic interactions.

The $\Phi$ index focuses on absolute differences between the amount of behaviour that individuals address to others and the amount of behaviour they receive from their partners in the group and permits describing social systems at individual, dyadic, and group level. A two-way matrix, called matrix **X**, contains the number of behaviours that each individual addresses to their partners and the behaviours that he/she receives from them in return. By means of the partitioning proposed by Constantine and Gower (1978), this sociomatrix **X** is additionally decomposed into its symmetrical and skew-symmetrical parts (matrices **S** and **K**, respectively): **X** = **S**+**K**, where **S** = (**X**+**X'**)/2 and **K** = (**X**−**X'**)/2, being **X** the original sociomatrix and **X'** its transpose. The elements of matrix **S** and **K** are denoted by $s_{ij}$ and $k_{ij}$, respectively. The $k_{ij}$ elements correspond to the skew-symmetrical part within each dyadic social interaction (i.e., the dyadic average of differences for all dyads). The $s_{ij}$ elements represent the dyadic reciprocity, in other words, the average of total behaviour within dyads. $\Phi$ is computed taking into account the ratio between the sum of squared values due to skew-symmetry and the total sum of squared values. The computation of the global symmetry index $\Phi$ is as follows:

$$\Phi = \sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} k_{ij}^2 \Bigg/ \sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} x_{ij}^2 ; \quad 0 \le \Phi \le .5$$

$\Phi$ denotes the proportion of skew-symmetry, ranging from *0*, maximum social reciprocity, to *.5*, lack of dyadic reciprocity in the social system.

The computation of the global symmetry index $\Psi$, which is complementary to $\Phi$, since $\Psi + \Phi = 1$, is as follows:

$$\Psi = \sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} s_{ij}^2 \Bigg/ \sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} x_{ij}^2 ; \quad 0.5 \le \Psi \le 1$$

The whole contribution to the symmetry ($\psi_j$) can be obtained as follows:

$$\Psi = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} s_{ij}^2}{\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} x_{ij}^2} = \sum_{j=1}^{n} \frac{\sum_{i=1}^{n} s_{ji}^2}{\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} x_{ij}^2} = \sum_{j=1}^{n} \frac{\mathbf{s}_j^{'}\mathbf{s}_j}{\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n} x_{ij}^2} = \sum_{j=1}^{n}\psi_j ; \quad .5 < \psi_j \le \Psi ; \quad \sum_{j=1}^{n}\frac{\psi_j}{\Psi} = 1$$

However, these measures are affected by the degree of agents' activity. Therefore, a normalized measurement is required. In order to obtain it, Solanas et al. (2006) recommend calculating a standardized skew-symmetry and symmetry measures as a result of dividing the $\varphi_j$ and $\psi_j$ agents' contributions by their total contribution ($\eta_j = \psi_j + \varphi_j$). Now the individual contribution to the skew-symmetry ($\upsilon_i$) and symmetry ($\lambda_i$) can be written as follows:

$$\upsilon_j = \frac{\varphi_j}{\eta_j} = 1 - \frac{\psi_j}{\eta_j} = 1 - \lambda_j ; \quad 0 \le \upsilon_j < .5; \quad .5 < \lambda_j \le 1; \quad \upsilon_j + \lambda_j = 1; \quad \sum_{j=1}^{n}\eta_j = 1$$

Social reciprocity can also be quantified at dyadic level. In the following expression, the ratios $\lambda_{i\leftarrow j}$ and $\upsilon_{i\leftarrow j}$ correspond to the symmetry and skew-symmetry parts of agent *j* assigned to agent *i*, respectively:

$$\sum_{j=1}^{n}\frac{\psi_j+\varphi_j}{\eta_j}=\sum_{j=1}^{n}\frac{\psi_j}{\eta_j}+\sum_{j=1}^{n}\frac{\varphi_j}{\eta_j}=\sum_{j=1}^{n}\sum_{i=1}^{n}\frac{s_{ij}^2}{\mathbf{s}_\mathbf{j}^{'}\mathbf{s}_\mathbf{j}+\mathbf{k}_\mathbf{j}^{'}\mathbf{k}_\mathbf{j}}+\sum_{j=1}^{n}\sum_{i=1}^{n}\frac{k_{ij}^2}{\mathbf{s}_\mathbf{j}^{'}\mathbf{s}_\mathbf{j}+\mathbf{k}_\mathbf{j}^{'}\mathbf{k}_\mathbf{j}}$$

$$=\sum_{j=1}^{n}\sum_{i=1}^{n}\lambda_{i\leftarrow j}+\sum_{j=1}^{n}\sum_{i=1}^{n}\upsilon_{i\leftarrow j}=\sum_{j=1}^{n}\lambda_j+\sum_{j=1}^{n}\upsilon_j=\sum_{j=1}^{n}\lambda_j+\upsilon_j=n$$

Researchers can study patterns of reciprocity in groups using group measures as the DC or $\Phi$ statistics, as well as individual and dyadic contributions to asymmetry by means of the $\Phi$ statistic. Inferences represent a natural follow-up to description, testing null hypothesis as, for instance, complete reciprocation among individuals. The following section refers to a statistical technique enabling social researchers to make decisions on testing social reciprocity at group, dyadic and individual levels.

## 3.- A statistical procedure for testing social reciprocity

As regards statistical decision making, the main problem of the DC and $\Phi$ statistics is that their exact sampling distributions are unknown and it should be derived for each particular group size and dyadic interaction frequency and there is no one-to-one correspondence between the sociomatrix configurations and the values of the statistics. It is only feasible to compute exact sampling distributions with small group sizes and small dyadic interaction frequencies, since with the increment of $n$ and $N_{ij}$ (i.e., the number of behaviours in dyad $ij$), the number of possible configurations increases exponentially. Monte Carlo procedures can be used to estimate the sampling distribution of the statistics and to test the null hypothesis that a sample was randomly drawn from a specified population (Noreen, 1989). The mathematical model underlying the Monte Carlo procedure entails several assumptions. First, it is assumed that the probability of the event "individual $i$ addresses behaviour to individual $j$" does not change (i.e., $p_{ij}$ is constant), since round-robin designs imply aggregating different occasions of interaction across time in a single sociomatrix (Boyd & Silk, 1983; Tufto, Solberg, & Ringsby, 1998). Second, the outcomes of the consecutive interactions during the observation period are assumed independent (Appleby, 1983; Boyd & Silk, 1983), since aggregation makes impossible the estimation of potential dependence and there is no strategy for controlling order effects is currently not available (Kenny et al., 2006). The assumption permits modelling the distribution of $X_{ij}$ by a binomial distribution with parameters $N_{ij}$ and $p_{ij}$, a probabilistic approach used in social interactions studies (Tufto et al., 1998). Third, dyads are assumed independent. The last two assumptions are also needed in the SRM (Kenny et al., 2006; Warner et al., 1979).

The Monte Carlo procedure generates sociomatrices according to parameter $p_{ij}$, which arises from the specific null hypothesis of the applied researcher. Statistical significance (i.e., a $p$ value) is obtained locating statistics' values for the original data in the respective sampling distributions. This objective is achieved following nine steps:

1) Select a test statistic: DC and the $\Phi$ statistics at group level, as well as the dyadic and individual contributions to the asymmetry.

2) Define the population: Specify matrix **Π** with the parameters $p_{ij}$ corresponding to the symmetry levels in each dyad. The procedure is flexible and can be applied to any null hypothesis. For instance, the null hypothesis of complete reciprocation stating that dyadic relations are symmetrical among all individuals can be represented as $H_0$: $p_{ij} = p_{ji} = .5$. The corresponding matrix **Π** will be specified as follows:

$$\mathbf{\Pi} = \begin{pmatrix} 0 & 0.5 & \cdots & 0.5 \\ 0.5 & 0 & \cdots & 0.5 \\ \vdots & \vdots & \ddots & \vdots \\ 0.5 & 0.5 & \cdots & 0 \end{pmatrix}$$

3) Input the original sociomatrix, from which the matrix **N** that contains the parameters $N_{ij}$ (number of behaviours in a dyad) can be obtained. Since the behaviours in a dyad are complementary (i.e., $N_{ij} = x_{ij} + x_{ji}$), matrix **N** is a symmetrical one. The size of the original sociomatrix determines *n* (group size).

4) Compute the outcome: the statistics values corresponding to group, dyadic, and individual levels are computed for the original sociomatrix.

5) Set *NS*, the number of simulated sociomatrices used to estimate the sampling distributions for all the statistics. For instance, NS can be set to *99,999*.

6) Set the iterations controlling counters *iter* and *nge* counters to *0*.

7) Draw a sample from the specified population and compute its pseudostatistic: indices at different levels of analysis are computed for this drawn sociomatrix. Then compare these pseudostatistics with the original statistics. A detailed description of the measures and the computation of their corresponding *nsc* is shown in Table 1. For instance, in the case of the DC statistic, if pseudostatistic is as large as or larger than the original value then add *1* to the *nge* counter and then go to step 8). Otherwise, if a pseudostatistic is lower than the original value then go directly to step 8).

| Statistics | Level of analysis | Computation of nsc |
|---|---|---|
| DC | Group | Greater than or equal |
| $\Phi$ | Group | Greater than or equal |
| $\Psi$ | Group | Less than or equal |
| $\lambda_j$ | Individual | Less than or equal |
| $\upsilon_j$ | Individual | Greater than or equal |
| $\upsilon_{i\leftarrow j}/\upsilon_j$ | Dyadic | Greater than or equal |

*Table 1.* Summary of some of the measures of social reciprocity provided by the R package, their corresponding level of analysis and an explanation of the computation of the significant cases (*nsc*).

8) Add *1* to the *iter* counter and repeat step 7) till *iter* counter equals *NS*. In the example the step 7) will be iterated till *iter* equals *99,999*.

9) Compute the significance level: the *p* value is computed as (nge + 1)/(NS + 1), where *NS* equals the number of the generated matrices and *nge* is the number of significant cases. This is a valid statistical test as it ensures that the original statistic is among the set of simulated statistics, thus, the *p* value can never be smaller than 1/rep (Noreen, 1989; Onghena & May, 1995).

## 4. - An R package for testing social reciprocity

An R package (*reciprocity v.0.1*, available upon request) has been developed in order to compute social reciprocity statistics and obtain their statistical significance by means of a Monte Carlo test. This software can be useful for social psychologists and ethologists as it includes indices that allow them to measure social processes and make decisions about dyadic interactions in groups at group, dyadic, and individual levels.

Firstly, the sociomatrix to analyse has to be specified following a predefined format. If the matrix is in a text file, data can be loaded in a matrix called **X**. The name of the file has to be specified as well as the number of rows as it is shown below:

```
X <- matrix(scan("<filename>"),nrow=<number>,byrow=T)
```

Secondly, researchers can choose the number of matrices they want to generate (*rep*). Afterwards, the matrix **Π** of probabilities of the event of interest has to be defined according to the null hypothesis of interest. If this matrix of $p_{ij}$, called *pi* in the R program, is in a file, then it has to be loaded as follows:

```
pi <- matrix(scan("<filename>"),nrow=<number>,byrow=T)
```

The function *reciptest* has been developed in order to carry out the Monte Carlo sampling. It yields *p* values for social reciprocity statistics at group, dyadic and individual levels depending on the options selected:

```
reciptest(X,pi,rep,overlev=<TRUE/FALSE>,indivlev=<TRUE/FAL
SE>,dyadlev=<TRUE/FALSE>,names,label=<TRUE/FALSE>)
```

To generate sociomatrices (called *matgen*), a C program (*recip.c*) is called by the *reciptest* function. The simulation steps are as follows: a) group size is defined according to the size of the original matrix; b) a random number *a* is generated from a binomial distribution with parameters $N_{ij}$ and $p_{ij}$, specifically *dyadc* and *pi*; c) the random number is assigned to the element on the upper triangular matrix ($x_{ij}$) and the value on the lower triangular matrix is obtained by the formula $x_{ji} = N_{ij} - x_{ij}$; d) if the element belongs to the principal diagonal, a *0* value is assigned; e) steps b) to c) are repeated for each element in the matrix; f) once the *matgen* has been generated, the program computes the social reciprocity statistics associated to this simulated sociomatrix; and g) steps b) to f) are repeated according to the number of iterations previously specified (*rep*). In order to obtain statistical significance, the *p* value is obtained by means of the formula shown above and the criteria of Table 1.

## 5.- An illustrative example

In this section the procedure is applied to data collected in the context of aggression in children research (Kenny et al., 2007). A group of six third-grade children is observed in order to quantify the dyadic aggression in play context. Table 2 shows the round-robin design data. Each cell contains the amount of aggressive behaviours addressed and received. Rows represent number of aggressions initiated by individuals and columns show the number of aggressions that each child receives from their partners.

| | **Partner** | | | | | |
|---|---|---|---|---|---|---|
| **ctor** | **h1** | **h2** | **h3** | **h4** | **h5** | **h6** |
| **h1** | | 7 | 2 | 7 | 1 | 4 |
| **h2** | 5 | | | 5 | 8 | 28 |
| **h3** | 0 | 9 | | 9 | 9 | 9 |
| **h4** | 0 | 8 | 7 | | 3 | 94 |
| **h5** | 5 | | | 40 | | 6 |
| **h6** | | 7 | 1 | 72 | 1 | |

*Table 2* Round-robin design in which aggression among third-grade children is studied. Extracted with permission from Kenny et al. (2007).

Researchers can be interested in detecting how symmetrical children's aggressions are in order to apply a more effective psychological technique directed to a specific child. Although the empirical values for the DC (.236) and $\Phi$ (.034) seem to suggest that the group is close to complete reciprocation, an asymmetrical pattern in the aggressive behaviour of the group was found significant ($p$ value = .00001 for both statistics). The results of the Monte Carlo sampling using *99,999* replications shown in Table 3 confirm that fact – the means for both statistics under the hypothesis of complete reciprocation are lower than the empirical values. The non reciprocal pattern of aggressive behaviour in the group means that there will be at least one individual who mainly behaves more aggressively than the others.

| | *DC* | *Φ* |
|---|---|---|
| **Original Statistical value** | .236 | .034 |
| ***p* value** | .00001 | .00001 |
| **N simulations** | 99,999 | 99,999 |
| **Mean** | .0656 | .0036 |
| **Variance** | .000212 | .000004 |
| **Maximum** | .143 | .023 |
| **Minimum** | .0191 | .0002 |
| **25th Percentile** | .0549 | .0022 |
| **50th Percentile** | .0641 | .0032 |
| **75th Percentile** | .0745 | .0045 |

*Table 3.* Some results of the Monte Carlo test for aggressive behaviour data for the 6-children group under null hypothesis $p_{ij}$ = *.5*. Both indices were significant (DC = .236, *p* value = .00001; *Φ* = .034, *p* value = .00001).

As regards individual contributions to symmetry (quantified by λ) and skew symmetry (υ), the results presented in Table 4 show a significant skew-symmetrical part for all individuals (*p* value < .01). Individuals *2* ($\upsilon_{Ch2}$ = .101) and *3* ($\upsilon_{Ch3}$ = .197) show a larger skew-symmetrical pattern in comparison to the one shown by the other children in the group. The original sociomatrix shows that both address an important amount of aggression to their partners and receive less aggressive behaviour from them. Additionally, all children contribute significantly (*p* value < .01) to the symmetry in a high degree, being child *6* the main contributor to the symmetry part ($\lambda_{Ch6}$ = .988). Her/his high level of aggression with individual *4* is highly remarkable.

| **Membership** | $\lambda_j$ | $\upsilon_j$ |
|---|---|---|
| **Ch1** | $.915^{**}$ | $.085^{**}$ |
| **Ch2** | $.899^{**}$ | $.101^{**}$ |
| **Ch3** | $.803^{**}$ | $.197^{**}$ |
| **Ch4** | $.978^{**}$ | $.022^{**}$ |
| **Ch5** | $.937^{**}$ | $.063^{**}$ |
| **Ch6** | $.988^{**}$ | $.012^{**}$ |

*Table 4.* Standardized individual contributions to the skew symmetry ($\upsilon_j$) and to the symmetry ($\lambda_j$) for each the *6* children in the sociomatrix. ** = *p* value < .01.

The dyadic decomposition of the skew-symmetrical part is shown in Table 5. There is only one dyadic relation for which the skew-symmetry of a child can be mainly explained by her/his relation to another. Specifically, the skew-symmetrical pattern shown by child *6* can mainly be assigned to her/his interactions with child *3* ($\upsilon_{Ch3\leftarrow Ch6}/\upsilon_{Ch6}$ = .506; *p* value = .044).

| **Agent *j*** | | | | | | |
|---|---|---|---|---|---|---|
| **Agent *i*** | **Ch1** | **Ch2** | **Ch3** | **Ch4** | **Ch5** | **Ch6** |
| **Ch1** | 0 | $.001^{ns}$ | $.009^{ns}$ | $.077^{ns}$ | $.052^{ns}$ | $.014^{ns}$ |
| **Ch2** | $.004^{ns}$ | 0 | $.392^{ns}$ | $.343^{ns}$ | $.026^{ns}$ | $.369^{ns}$ |
| **Ch3** | $.061^{ns}$ | $.358^{ns}$ | 0 | $.186^{ns}$ | $.059^{ns}$ | $.505^{*}$ |
| **Ch4** | $.690^{ns}$ | $.414^{ns}$ | $.246^{ns}$ | 0 | $.856^{ns}$ | $.106^{ns}$ |
| **Ch5** | $.185^{ns}$ | $.013^{ns}$ | $.031^{ns}$ | $.343^{ns}$ | 0 | $.005^{ns}$ |
| **Ch6** | $.061^{ns}$ | $.214^{ns}$ | $.322^{ns}$ | $.051^{ns}$ | $.007^{ns}$ | 0 |
| **TOTAL** | 1 | 1 | 1 | 1 | 1 | 1 |

*Table 5.* Dyadic decomposition of the skew-symmetrical part in the aggression among *6* children ($\upsilon_{i\leftarrow j}/\upsilon_j$). Ns = non significant; * = *p* value < .05.

## 6.- Discussion

The present paper focuses on the quantification of social reciprocity, specifically on two overall indices, the DC index (van Hooff & Wensing, 1987) and the $\Phi$ index (Solanas et al., 2006). The $\Phi$ index also allows researchers to measure social reciprocity at different levels of analysis, specifically at individual and dyadic levels. Both DC and $\Phi$ are based on dyadic discrepancies, rather than on correlation, and present similar statistical properties (Leiva, Solanas, & Salafranca, 2008; Solanas, Leiva, & Salafranca, in press). Given that most researchers require procedures not only for describing social systems as a whole but also for making statistical decisions, an overall statistical technique based on Monte Carlo sampling is proposed. A potentially interesting null hypothesis to test is the one of complete reciprocation, although the statistical procedure allows testing other hypotheses regarding reciprocity and it is appropriate for a wide set of conditions.

The proposed procedure requires several assumptions to make statistical decisions. Specifically, it is assumed that $p_{ij}$ values are constant for each observation time, outcomes of successive interactions are independent and dyads are independent from each other. These assumptions are common to most of the statistical models for analysing social interaction (de Vries, 1995; Hemelrijk, 1990a; Kenny et al., 2006).

An implementation in free software for the measures and statistical tests here presented has been developed in order to be used by applied researchers. Nevertheless, some other programmes can be found in order to measure and make decisions regarding several social aspects as dyadic nonindependence, social dominance, and hierarchy (Alferes & Kenny, 2009; Campbell & Kashy, 2002; de Vries, Netto, & Hanegraaf, 1993; O'Connor, 2004).

To sum up, an overall procedure for testing social reciprocity by means of several measures founded on dyadic interactions has been reviewed and illustrated. This procedure could be useful in fields like social psychology and ethology in order to study group dynamics. An R program that allows social researchers to analyse any sociomatrix and make statistical decisions under different null hypotheses regarding social reciprocity has been developed.

## 7. - References

Alferes, V. R., & Kenny, D. A. (2009). SPSS programs for the measurement of nonindependence in standard dyadic designs. *Behavior Research Methods, 41*, 47-54.

Appleby, M. C. (1983). The probability of linearity in hierarchies. *Animal Behaviour*, *31*, 600-608.

Boyd, R., & Silk, J. B. (1983). A method for assigning cardinal dominance ranks. *Animal Behaviour*, *31*, 45-58.

Campbell, L., & Kashy, D. A. (2002). Estimating, actor, partner, and interaction effects for dyadic data using PROC MIXED and HLM: A user-friendly guide. *Personal Relationships*, *9*, 327-342.

Constantine, A. G., & Gower, J. C. (1978). Graphical representation of asymmetric matrices. *Applied Statistics*, *27*, 297-304.

Cook, W. L. (1994). A structural equation model of dyadic relationships within the family system. *Journal of Consulting and Clinical Psychology*, *62*, 500-510.

Cook, W. L. (2005). The SRM approach to family assessment. An introduction and case example. *European Journal of Psychological Assessment, 21*, 216-225.

Cook, W. L., & Kenny, D. A. (2004). Application of the Social Relations Model to family assessment. *Journal of Family Psychology*, *18*, 361-371.

Côté, S. D. (2000). Determining social rank in ungulates: A comparison of aggressive interactions recorded at a bait site and under natural conditions. *Ethology*, *106*, 945-955.

Dabos, G. E., & Rousseau, D. M. (2004). Mutuality and reciprocity in the psychological contracts of employees and employers. *Journal of Applied Psychology*, *89*, 52-72.

de Vries, H. (1995). An improved test of linearity in dominance hierarchies containing unknown or tied relationships. *Animal Behaviour, 50*, 1375-1389.

de Vries, H., Netto, W. J., & Hanegraaf, L. H. (1993). MatMan: A program for the analysis of sociometric matrices and behavioural transition matrices. *Behaviour, 125*, 157-175.

Gill, P. S., & Swartz, T. B. (2001). Statistical analyses for round robin interaction data. *The Canadian Journal of Statistics, 29*, 321-331.

Gouldner, A. W. (1960). The norm of reciprocity: A preliminary statement. *American Sociological Review, 25*, 161-178.

Hemelrijk, C. K. (1990a). A matrix partial correlation test used in investigations of reciprocity and other social interaction patterns at group level. *Journal of Theoretical Biology*, *143*, 405-420.

Hemelrijk, C. K. (1990b). Models of, and tests for, reciprocity, unidirectionality and other social interaction patterns at a group level. *Animal Behaviour*, *39*, 1013-1029.

Howe, N., & Recchia, H. (2005). Playmates and teachers: Reciprocal and complementary interactions between siblings. *Journal of Family Psychology, 19*, 497-502.

Kenny, D. A., Albright, L., & Malloy, T. E. (1988). Consensus in personality judgements at zero acquaintance. *Journal of Personality and Social Psychology*, *56*, 506-518.

Kenny, D. A., & Judd, C. M. (1986). Consequences of violating the independence assumption in analysis of variance. *Psychological Bulletin*, *99*, 422-431.

Kenny, D. A., Kashy, D. A., & Cook, W. L. (2006). *Dyadic data analysis*. New York: Guilford Press.

Kenny, D. A., & La Voie, L. J. (1984). The social relations model. In L. Berkovitz (Ed.), *Advances in experimental psychology* (Vol. 18, pp. 142-182). San Diego, CA: Academic Press.

Kenny, D. A., Mohr, C. D., & Levesque, M. J. (2001). A social relations variance partitioning of dyadic behavior. *Psychological Bulletin*, *127,* 128-141.

Kenny, D. A., & Nasby, W. (1980). Splitting the reciprocity correlation. *Journal of Personality and Social Psychology, 38*, 249-256.

Kenny, D. A., West, T. V., Cillessen, A. H. N., Coie, J. D., Dodge, K. A., Hubbard, J. A., et al. (2007). Accuracy in the judgment of aggressiveness. *Personality and Social Psychology Bulletin*, *33*, 1225-1236.

Lashley, R. B., & Bond, C. F., Jr. (1997). Significance testing for round robin data. *Psychological Methods*, *2*, 278-291.

Leiva, D., Solanas, A., & Salafranca, Ll. (2008). Testing reciprocity in social interactions: A comparison between the directional consistency and skew-symmetry statistics. *Behavior Research Methods*, 40, 626-634.

Liang, J., Krause, N. M., & Bennett, J. M. (2001). Social exchange and well-being: Is giving better than receiving? *Psychology and Aging*, *16*, 511-523.

Malloy, T. E., & Albright, L. (2001). Multiple and single interaction dyadic research designs: Conceptual and analytic issues. *Basic and Applied Social Psychology*, *23,* 1-19.

Mantel, N. (1967). The detection of disease clustering and a generalized regression approach. *Cancer Research*, *27*, 209-220.

Noreen, E. W. (1989). *Computer-intensive methods for testing hypotheses: An introduction*. New York: Wiley.

O'Connor, B. P. (2004). SPSS and SAS programs for addressing interdependence and basic levels-of-analysis issues in psychological data. *Behavior Research Methods, Instruments & Computers*, *36*, 17-28.

Onghena, P., & May, R. B. (1995). Pitfalls in computing and interpreting randomization test *p* values: A commentary on Chen and Dunlap. *Behavior Research Methods, Instruments, & Computers*, *27*, 408-411.

Pelletier, F., & Festa-Bianchet, M. **(**2006). Sexual selection and social rank in bighorn rams. *Animal Behaviour, 71*, 649-655.

Solanas, A., Leiva, D., & Salafranca., Ll. (in press). Bias and standard error for social reciprocity measurements. *British Journal of Mathematical and Statistical Psychology*.

Solanas, A., Salafranca, Ll., Riba, C., Sierra, V., & Leiva, D. (2006). Quantifying social asymmetric structures. *Behavior Research Methods*, *38*, 390-399.

Stevens, J. M. G., Vervaecke, H., de Vries, H., & van Elsacker, L. (2005). Peering is not a formal indicator of subordination in bonobos (*Pan Paniscus*). *American Journal of Primatology*, *65*, 255-267.

Tufto, J., Solberg, E. J., & Ringsby, T. (1998). Statistical models of transitive and intransitive dominance structures. *Animal Behaviour, 55*, 1489-1498.

Väänänen, A., Buunk, B. P., Kivimäki, M., Pentti, J., & Vahtera, J. (2005). When it is better to give than to receive: Long-term health effects of perceived reciprocity in support exchange. *Journal of Personality and Social Psychology*, *89*, 176-193.

van Hooff, J. A. R. A. M., & Wensing, J. A. B. (1987). Dominance and its behavioral measures in a captive wolf pack. In H. W. Frank (Ed.), *Man and wolf* (pp. 219-252). Dordrecht: Junk Publishers.

Vogel, E. R. (2005). Rank differences in energy intake rates in white-faced capuchin monkeys, *Cebus capucinus*: The effects of contest competition. *Behavioral Ecology and Sociobiology, 58*, 333-344.

Warner, R. M., Kenny, D. A., & Stoto, M. (1979). A new round-robin analysis of variance for social interaction data. *Journal of Personality and Social Psychology*, *37*, 1742-1757.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge: Cambridge University Press.

Wayne, S. J., Shore, L. M., Bommer, W. H., & Tetrick, L. E. (2002). The role of fair treatment and rewards in perceptions of organizational support and leader–member exchange. *Journal of Applied Psychology*, *87*, 590-598.